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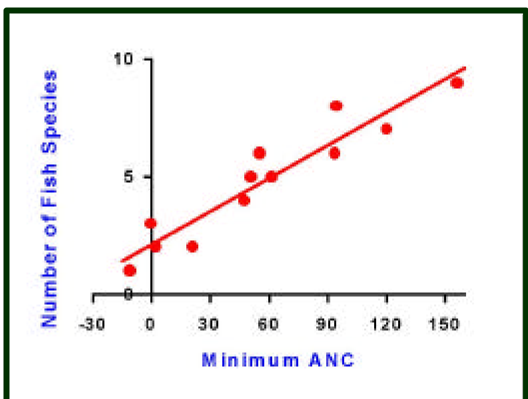
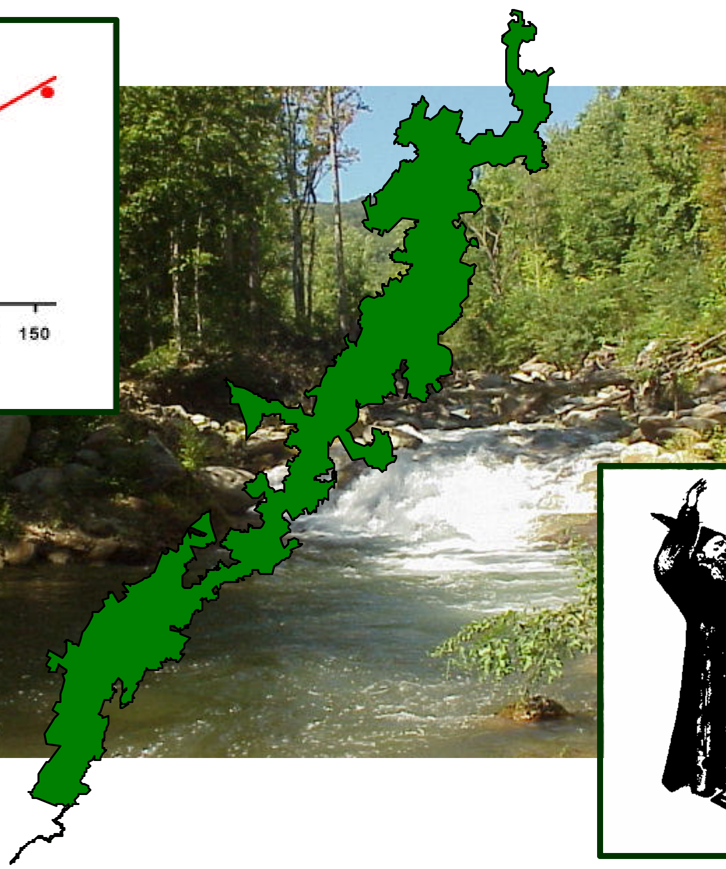
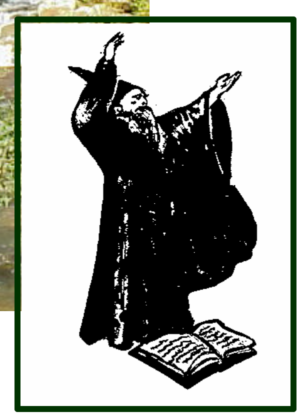
Shenandoah National Park: Fish In Sensitive Habitats

Project Final Report - Volume III

Basin-wide Habitat and Population Inventories, and Behavioral Responses to Acid in a Laboratory Stream







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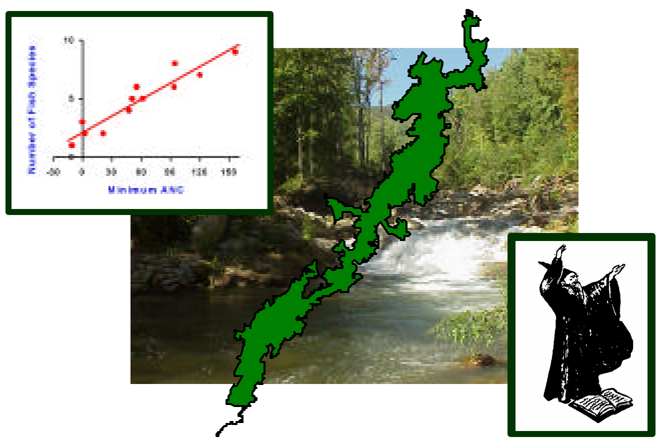

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Chapter 5A

Influence of Water Quality and Physical Habitat on Brook Char and Blacknose Dace in Three Streams with Different Acid Neutralizing Capacities in Shenandoah National Park, Virginia

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Abstract

We compared the types, distribution, and total amount of habitat available to fish populations; fish community structure; and abundance of fishes common to three headwater streams of different acid neutralizing capacity (ANC; low, moderate, and high) within Shenandoah National Park, Virginia. No difference existed in the total amount of wetted habitat available to fish populations among the three streams. However, differences were identified in the depth and substrate sizes observed in both pool and riffle habitat among streams ($P<0.05$). Pool to riffle ratios (P:R) ranged from 1.1 to 2.2 among streams. Fish species richness ranged from three to seven species, and increased with ANC. Brook char (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*) were the only species common to all three streams. Both species used pools more than riffles ($P<0.05$). Brook char density in pools increased with ANC ($P<0.05$), and ranged from 13.1 to 40.1 fish/100m^2. Blacknose dace density in pools was similar between the low ANC stream (23.2 fish/100m^2) and the high ANC stream

(22 fish/100m^2) in spring of 1993, but eventually became higher in the low ANC stream ($P<0.05$). Deteriorating water quality conditions associated with acidification (e.g., pH and alkalinity) appeared more important in determining the success of brook char than blacknose dace in these streams, despite the likelihood that blacknose dace are more acid sensitive than are brook char.

Introduction

Nearly two decades ago, surface waters of the Mid-Appalachian region were identified as susceptible to anthropogenic acidification, resulting from increases in acidic deposition on watersheds with minimal acid-neutralizing capacity (ANC) (Galloway and Cowling 1978). Extensive examination of the acid-base status of headwater streams in the mountains of Shenandoah National Park (SNP) were initiated shortly thereafter, and have continued to the present time (Webb 1994). Information linking stream acidification with geology, base-flow water chemistry, and hydrologic pathways have improved our understanding of chronic degradation to these sensitive watersheds. Concern remains high, however, about the effects of extreme environmental conditions during short-term acidic episodes, and the impact of episodes on fish communities. Although several studies have examined the relationship between water chemistry and fish occurrence and the response of individual fish species, important questions concerning fish community responses to acidic episodes remain unanswered.

Aquatic organisms, including fish at all trophic levels, are adversely affected by reduction in pH and increases in concentrations of toxic metals. Abundance, growth, and production of valuable commercial and recreational species have been reduced, and sensitive species have been lost because of acidic deposition (Haines 1981). To fully understand the impacts of acidic deposition on important fisheries resources, we need to establish linkages between physical habitat characteristics and water quality conditions. We have developed those linkages for three SNP streams including Paine Run (low ANC), Staunton River (moderate ANC), and Piney River (high ANC). We described physical habitat characteristics available to fish populations, linked physical habitat data with information on specific water quality characteristics, assessed differences among study streams for all of the variables measured, and explored the contributions of physical habitat and water quality characteristics to observable responses in the fish communities.

Study Sites

Headwaters for each watershed lie within the boundaries of Shenandoah National Park, Virginia (Figure 5A-1). The low ANC stream, Paine Run, is located in the Southern District of SNP. Second-order Paine Run flows west from an elevation of about 730 meters over mostly silica-clastic bedrock (91% Hampton and 9% Antietam) to its confluence with the South River and has a mean width of 4 m. Riparian vegetation is 96% chestnut oak and pine, and 4% hemlock, yellow poplar, and cove hardwoods.

Moderately sensitive Staunton River is a second-order stream that flows east from an elevation of about 960 meters over mostly granitic bedrock (92% Pedlar, 8% Old Rag) through the central district of SNP to its confluence with the Rapidan River. Staunton River has a mean width of 4 m and riparian vegetation consisting of 48% chestnut oak and pine, 11% red oak and black locust, and 41% hemlock, yellow poplar, and cove hardwoods.

Piney River is a well buffered second-order stream originating at about 970 meters elevation. Pine River flows east over mostly basaltic bedrock (68% Catoctin, 32% Pedlar) through the Northern District of SNP to its confluence with the North Fork of the Thornton River and has a mean width of 4 m. Riparian vegetation in this watershed is 36% chestnut oak and pine, 18% red oak and black locust, and 46% hemlock, yellow poplar, and cove hardwoods.

Methods

Physical Habitat

We used the basinwide visual estimation technique (BVET; Hankin and Reeves 1988) to collect a large amount of data associated with individual habitat units located throughout each basin. Habitat and fish populations were surveyed by the same two person crew during the summer of 1993 (June - August). All main branches were surveyed starting at the SNP boundary or at a confluence with another stream. Tributaries were surveyed only if they had sufficient water to support fish, which was determined by the field crew. Surveys were concluded when, in the opinion of the crew leader, the habitat became unable to support fish, i.e. no water. In practice, this occurred when the stream emerged from underground or simply "went dry."

Data collected included the type of every habitat unit, estimates of habitat unit length and wetted channel area, maximum and mean depth, substrate composition (dominant and subdominant), and number of pieces of large woody debris (LWD) in different size categories. Habitat types were limited to pools and riffles following descriptions by Bisson et. al (1982). Substrate was assigned to one of nine size classes; the dominant-covering the major percentage of the bottom of a selected habitat, and subdominant-covering the second highest percentage of the bottom, were identified and recorded for each habitat unit. The number of LWD pieces in each of seven size classes were recorded along with other significant features that were suspected to influence fish populations (e.g. landslides, tributary junctions, bridge and trail crossings, and major changes in riparian vegetation).

We measured habitat features in a systematic random sample of 20 percent of all pools and 10 percent of all riffles to verify and calibrate our estimates. Measurements were made using a hip-chain, a twenty meter tape-measure, and a wading-rod graduated in centimeters.

Fish population survey

We determined the sampling fraction (relative proportions of habitat units by habitat type) before each sampling period according to a stratified random design based on the size and location of habitat units in the drainage and their perceived importance to fish. Each habitat unit was numbered in sequence beginning at the downstream end of each sampled reach, and random numbers were chosen as the starting points for selection of units for measurement. A typical sequence included every 5th (20%) pool and every 10th (10%) riffle. In smaller reaches every 3rd (33%) pool and every 5th (20%) riffle was sampled to make sure we had enough paired samples.

Fish populations were censused by divers equipped with face mask, snorkel, and writing slate. Divers carefully entered each selected habitat unit and recorded the species, numbers, and relative size (i.e. age 0+, 1+, and 2+ for brook trout) of all fish observed. After completing the observations at a habitat unit, the recorder attached an identifying flag in a conspicuous location to be referenced during the next phase of population sampling.

After the underwater observations were completed in the sub-basin, the sampling crew selected a fraction (approximately 10%) of the total number of units snorkeled in which to conduct a multiple-pass removal census (Zippen 1958) with a backpack electroshocker (700V AC) and dip nets . All fish were identified, measured for fork length (mm) and total length (mm), and weighed (0.1 g) before being returned to their approximate location of capture. Electrofishing was essential for two reasons: (1) to verify identifications and counts made by divers; and, (2) to obtain accurate measurements of length and weight.

Total lengths of fish were used to calculate length frequencies for blacknose dace and brook trout. Population estimates for each species (including age 0+ brook trout) were calculated, and diver counts of fish number per unit of habitat area (density) were averaged for similar habitat types in each reach to obtain reach estimates of density. Habitat area used for calculating densities was truncated at limits of upstream fish distribution. The distribution for each species encompassed habitat from where individuals were first observed to where they were last seen by a diver in each reach.

Water Quality Characteristics

Water quality data used in this study included pH, alkalinity (μeq/L), and calcium (mg/L) (Table 5A-1.) Water quality data were derived from samples (n=38 in Paine Run, n=17 in Staunton River and n=29 in Piney River) taken along the entire length of each stream from the Park boundary to its underground source. Data for these variables were obtained from the University of Virginia's Department of Environmental Sciences which conducted a synoptic survey during the summer of 1993 in each of the three watersheds. These synoptic surveys coincided with the timing of habitat and fish population surveys.

All three streams were divided into contiguous reaches identified by changes in water quality characteristics or physical habitat features derived from the BVET habitat surveys (e.g., confluence of the main branch with a major tributary). Averages of the water quality data from all synoptic survey sampling sites within each reach were then assigned to the appropriate subset of habitat units. Paine Run (low ANC) had 7 reaches, Staunton River (moderate ANC) had 8, and Piney River (high ANC) had 11. Often, changes in water quality characteristics and a physical habitat landmark coincided to support the choice of a reach boundary. Each pool and riffle was then easily assigned to one of these reaches, using locations derived from hip-chain measurements (to the nearest 0.1 m) made during the BVET habitat surveys along the longitudinal axis of a stream, from its Park boundary to the upper extent habitable by fish.

Statistical analyses

Data were entered into a standard spreadsheet and compiled immediately after the surveys were completed. Results were summarized using Quattro Pro, Sigma Plot, Harvard Graphics, Presentations, Microfish, and PC-SAS. Examples of all calculations used to derive estimates of habitat and fish populations are available in Dolloff et al. (1993).

An analysis of variance on ranks (Kruskal-Wallis) was performed on all habitat, water quality, and fish data. To control the experimentwise error rate, all paired comparisons were made using Dunn's multiple comparison procedure. Examination of Kruskal-Wallis and Dunn's test results provided a means to determine differences among the streams, and to identify patterns among all streams in each group (e.g., brook char in pool habitat).

A principal component analysis (PCA) was used to explore the response of fish populations to physical habitat and water quality conditions. The PCA was performed first with habitat variables alone, and then with habitat and water quality variables combined. Displaying the results of these principal components analyses in two dimensions permits the examination of patterns in multidimensional space. Gauch (1982) showed that this type of display also suppressed "noise", because the first few principal components of the data (those with the largest variances), nearly always reflect the most persistent features of the environment.

Results

Physical Habitat and Fish Population Characteristics

Paine Run - Habitat was surveyed in over 10 km of Paine Run, including the main branch and three tributaries. In total, there were 453 pools and 402 riffles (Table 5A-2). Considerable overlapping of substrate classes occurred, with primary substrates ranging from sand to bedrock. Most of the LWD in the active channel of Paine Run (main branch) was either in root wads or in the small diameter classes (less than 10 cm).

Three fish species were found in the Paine Run watershed: brook char, blacknose dace, and fantail darter *Etheostoma flabellare*. Examination of the length frequency data from Paine Run indicated that the 1992 year class of brook char was missing. Similar conditions existed in several other western aspect streams within the Park. The reason for the apparent loss of the 1992 year class is unknown. The loss cannot be attributed to acidic conditions or events, as intensive monitoring of stream flow and water quality in Paine Run did not begin until summer 1992, well after emergence of young-of-year char would have been complete. Fantail darters were most common in the lower portion of the main branch of Paine Run.

Staunton River - Habitat was surveyed in over 10 km of Staunton River from its confluence with the Rapidan River to the upper extent habitable by fish. This included the main branch and three tributaries. In total, there were 398 pools and 185 riffles (Table 5A-2). Habitat in Garth Spring Run, with an average depth of less than 5 cm, consisted of a single riffle from its confluence with the main branch of Staunton River to its underground source. Considerable overlap in dominance of substrate classes occurred in the main branch of the Staunton River, where the streambed ranged from silt to bedrock. The diameter of most of the LWD was less than 10 cm, with very few pieces derived from mature trees (diameters greater than 50 cm).

Analysis of fish data from Staunton River showed greater diversity of fish species than in Paine Run. Brook char, blacknose dace, torrent sucker (*Moxostoma rhothoecum*), American eel (*Anguilla rostrata*), and rosyside dace (*Clinostomus funduloides*) were seen by divers and captured during electrofishing. No fish were seen in Garth Spring Run. Year classes 1991-93 for brook char were present in the sample from this east-side stream. Blacknose dace were present, but abundance was lowest in Staunton River among the three streams.

Piney River - Habitat was surveyed in over 10 km of Piney River from its SNP boundary to upper extent habitable by fish, including the main branch and its Right Fork. In total, there were 313 pools and 289 riffles (Table 5A-2). Habitat in the Right Fork of Piney River consisted of a single riffle from the third pool above the confluence with the main branch to its underground source; this riffle had an average depth of less than 5 cm. Once again, considerable overlap in dominance of substrate classes occurred in the main branch of Piney River; streambed composition ranged from silt to bedrock. Diameter of most LWD was less than 10 cm, also with few pieces derived from mature trees (diameters greater than 50 cm) and root wads.

Diversity of fish species in Piney River was greatest of the three streams. Brook char, blacknose dace, rosyside dace, American eel, longnose dace (*Rhinichthys cataractae*), mottled sculpin (*Cottus bairdi*), and river chub (*Nocomis micropogon*) were seen by divers and captured during electrofishing. Year classes 1991-93 of brook char were present in our sample from this east-side stream. Blacknose dace were present in the sample, and abundance was similar to that of Paine Run.

The basinwide visual estimates of total surface area (including tributaries) were similar among the three streams and are as follows: Paine Run = 32,945 m^2 (+/-818 m^2); Staunton River = 32,792 m^2 (+/-875 m^2); and, Piney River = 29,458 m^2 (+/-1,194 m^2). Estimates of total pool surface area in the main branch ranged from 8,464 m^2 (+/- 441 m^2) in Piney River to 10,358 m^2 (+/-461 m^2) in Paine Run (Table 5A-3). Estimates of total riffle surface area in the main branch ranged from 14,533 m^2 (+/-574 m^2) in Paine Run to 19,592 m^2 (+/-1,120 m^2) in Piney River (Table 5A-3).

Only two species were common to all three watersheds: brook char (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*). Consequently, all analyses of fish population responses were limited to these two indicator species.

Estimates of brook char abundance in the main branches ranged from 642 fish (+/-565 fish) in Paine Run riffles to 3,451 fish (+/-1,451 fish) in Piney River pools (Table 5A-4). Estimates of blacknose dace abundance in the main branches ranged from 147 fish (+/-449 fish) in Staunton River riffles to 2,404 fish (+/-746 fish) in Paine Run pools (Table 5A-5).

Combining basinwide estimates of abundance for each species with the estimates of habitat area provided estimates of population density (fish/100m^2) by species, habitat type, and reach. Brook char density ranged from 4 fish/100m^2 in Paine Run riffles to 41 fish/100m^2 in Piney River pools. Blacknose dace density ranged from 1 fish/100m^2 in Staunton River riffles to 23 fish/100m^2 in Paine Run pools. Density of both species was higher in pools than riffles for each stream. Brook char density in pool habitat increased with increasing ANC among the streams: Paine Run = 13 fish/100m^2, Staunton River = 25 fish/100m^2, and Piney River = 41 fish/100m^2. Density of blacknose dace in pools was similar between Paine Run and Piney River (23 fish/100m^2 and 22 fish/100m^2 respectively), and both were higher than that found in Staunton River (6 fish/100m^2). Lefthand Hollow, the lower-most tributary in Paine Run, had an exceptionally high density of blacknose dace in pools (78 fish/100m^2) in June 1993, but did not reflect a similar pattern the following summer. Riffle densities followed a similar pattern for each species among the streams, but was much less variable overall.

Statistical analyses

There were significant differences ($P<0.05$) in the density of brook char in pools among the three streams (Table 5A-6). Staunton River pool densities were not different from those in Piney River or Paine Run, but densities of char in Piney River pools were significantly greater than those in pools of Paine Run. A significant difference ($P<0.05$) in the densities of blacknose dace in pools also was found among the three streams; however, no significant difference existed in the density of blacknose dace in pools between Piney River and Paine Run. The densities of blacknose dace in pools of these two streams were significantly greater than the density found in the pools of Staunton River. Densities of brook char and blacknose dace in riffle habitat among the three streams were not significantly different.

Significant differences ($P<0.05$) were identified in pool habitat characteristics for maximum depth, average depth, and primary substrate. Staunton River had the deepest pools and the smallest primary substrates, while Paine Run was associated with the shallowest pools and largest substrates. Piney River was intermediate for both characteristics. No significant difference was identified among the three streams for any other pool habitat characteristics measured. Significant differences ($P<0.05$) were identified in the depth and substrate categories of the measured characteristics for riffle habitat. No difference was found in the depth of Staunton River and Paine Run riffles, while both were deeper than riffles in Piney River. Primary substrate was similar in Piney River and Staunton River riffles, and was smaller than that observed in Paine Run. Secondary substrate in Piney River riffles was larger than that found in the Staunton River. Secondary substrate in Paine Run riffles was intermediate in size and similar to the other two streams. No differences existed in the large woody debris loading of riffle habitat among the three streams.

Principal component analysis (PCA) was used to explore the contribution of physical habitat and water quality to observable fish population responses (e.g., are fish living in the habitat) for the two species common to all three watersheds. Because no significant difference in the numbers of either species was identified in riffle habitat among the streams, principal component analysis was limited to pools only. All measured habitat and water quality characteristics were included in this analysis.

Plots of the PCA scores for pools in which brook char were observed, on habitat variables alone (Figure 5A-2), and water quality with habitat variables combined (Figure 5A-3) demonstrate that both habitat and water quality were required to explain variation in fish density. The first two principal components explained nearly 55% of the variability in the data (Tables 5A-7 and 5A-8). Considerable overlap of the two components for habitat variables alone (Figure 5A-2) suggests there may be little difference in the response of brook char to the constituents of the components (e.g., PC1 = area and average depth, PC2 = primary substrate and large woody debris loading). Brook char did not seem to be strongly discriminating in their use of pool habitat among the streams on the basis of physical habitat characteristics alone, despite the fact that significant differences (ANOVA on ranks $P<0.0001$) existed for both depth and primary substrate. Combining habitat and water quality variables in the next PCA (Figure 5A-3), suggested a stronger response by brook char; most notable is the separation of Paine Run (relative low char density) from the other two streams on the basis of lower alkalinity and pH.

Plots of the PCA scores on habitat variables alone (Figure 5A-4), and water quality with habitat variables combined (Figure 5A-5) for blacknose dace in pools showed a pattern superficially similar to that observed for brook char. The first two principal components explained nearly 60% of the variability (Tables 5A-7 and 5A-8). Interpretation of blacknose dace habitat use based on these components, however, is more difficult. In the plot of habitat variables alone (Figure 5A-4), Staunton River fish (relative low blacknose dace abundance) appear to be isolated in the lower right quadrat. This response to the first principal component (PC1 = depth) suggests that the lower abundances are related to the significantly deeper water found in these pools (ANOVA on ranks $P<0.0001$). Staunton River fish appear to be further isolated on the basis of the second component (PC2 = surface area, primary substrate, and large woody debris loading). This provides further evidence that the lower abundances may also be related to the smaller surface area of pools, finer substrates, and increased LWD loading, although only primary substrate had been previously identified as significantly different among the streams (ANOVA $P<0.0001$). It follows that as pools become deeper and large woody debris loading increases, an increase in depositional zones where finer substrates can settle out of stream currents would be observed. When the water quality variables were included (Figure 5A-5), the only clear separation of the Staunton River fish from the other two streams occurs in the second component (PC2 = depth). This supports the evidence seen in the first PCA plot. No obvious separation in terms of pool utilization by dace, or relative abundance of the species is seen along the axis reflecting water quality, suggesting that in these three streams, water quality plays less of a role in the success of blacknose dace.

Discussion

We quantified physical habitat and fish populations in three streams with different levels of ANC to determine the influence of within-basin variability of habitat on fish communities. We observed differences in fish community composition; densities of species common to all three watersheds; depth and substrate size in pool habitat; and depth and substrate size in riffle habitat. The three streams had similar total surface area of wetted habitat available to fish populations, and had surface areas in both pool and riffle habitat.

Fish species richness increased with increasing ANC, and ranged from a total of three species in Paine Run (low ANC) to seven species in Piney River (high ANC). However, a lack of historical species composition data makes it impossible to attribute differences in the diversity of fish species to water quality. We limited our identifications of relationships between fish and variability in physical habitat to brook char and blacknose dace because they were the only species common to all three watersheds. Densities of both species differed in pool habitat, while no difference existed in the riffle habitat among streams, possibly reflecting a preference for pools. Consequently, we will focus our discussion on observed differences within the pool habitat alone.

Brook char density in pools increased with increasing ANC, but the only statistical difference was between Paine Run (low ANC) and Piney River (high ANC). The 1992 year class of brook char was missing from Paine Run, and undoubtedly contributed to the differences observed in abundance. Unfortunately, the apparent loss of the year class can not be explained on the basis of acidic conditions or other physical habitat limitations because this research began well after the 1992 year class would have completed emergence. Lennon (1961) linked occasional loss of brook char year classes to flood-drought cycles, and Neves and Pardue (1983) attributed the instability of brook char populations in headwater streams to similar environmental extremes and angling pressure. Continued monitoring of fish abundance and distribution, streamflow, and water quality may help determine the cause of similar future losses. Exploratory analysis of the relation between brook char abundance and variability in pool habitat among these streams suggested that the relative abundance of this species was linked to differences in the water quality variables alkalinity and pH (ANOVA on ranks, $P<0.0001$ for each). These results were not unexpected due to the susceptibility of early life stages (e.g., incubation of eggs and emergence of alevins), to acidification in poorly buffered streams. Gunn (1986) showed these life stages to be most susceptible due to the high probability of encountering acidic snowmelt runoff during the spring.

Blacknose dace abundance was similar in the pool habitat of Paine Run (low ANC) and Piney River (high ANC). Abundance in these streams was higher than that in the pools of Staunton River (moderate ANC). The relatively low density of blacknose dace in Staunton River pools may reflect a population response to physical habitat features, especially considering the suitable water quality measured in this stream (Table 5A-2). However, given the widespread distribution of blacknose dace in Virginia (Jenkins and Burkhead 1994), and in North America in general (Scott and Crossman, 1973, Trial et al. 1983), habitat features alone in Staunton River pools can not account for the observed difference in density. The possibility of increased competition with other species like rosyside dace, and increased predation by American eel likely play as great a role in the observable densities of blacknose dace in Staunton River. The lack of a difference in abundance between Paine Run and Piney River pools supports the conclusion that the identified physical habitat differences were more influential for the success of blacknose dace than was variability in water quality. There are some potential explanations for the lack of a difference on the basis of water quality variables. First, blacknose dace breed in May, June, and July, typically after water temperatures exceed 15.6 degC (Schwartz 1958). Water temperatures in these streams will not exceed that level until early summer. This reproductive timing could create a temporal isolation of critical life stages for blacknose dace from acidic episodes in these streams. Hence, no observable effect would be observed on the abundance of blacknose dace in Paine Run (the low ANC stream). This does not mean that acidic would not be detrimental to the population of blacknose dace in Paine Run, only that some protection may be offered to the susceptible life stages by the current timing of events. Secondly, blacknose dace typically are found in large, shallow pools of clear, small streams (Scott and Crossman 1973), with the highest densities of adults occurring over gravel-cobble substrates (Gibbons and Gee 1972). This relationship of the species to depth and substrate supports the exploratory analysis results, despite bioassay evidence that blacknose dace may be even more sensitive to acidification than brook char (Johnson et al. 1987). Furthermore, these results illustrate the limitations of laboratory bioassays and other conventional methods of assessing stress on aquatic organisms. Current approaches typically lack integration of all the environmental factors influencing chronic stress responses by organisms like fish at each lower level of biological organization

(Adams 1990). Consequently, the ability of these approaches to project ecological realities is limited. Investigations making complementary use of techniques from as many levels of biological organization as possible will improve on these inadequacies, and may help clarify the mechanisms behind conflicting responses like those observed for blacknose dace in Paine Run.

Both habitat complexity and water quality characteristics contributed to observed population responses of the two indicator species among the watersheds. There was both a reduction in fish species richness, and a significant reduction in the density of brook char as water quality characteristics related to acidification deteriorated. Many studies have demonstrated similar reductions in species composition and fish abundance resulting from surface water acidification (Altshuller and Linthurst 1984; Schindler 1987). On the other hand, despite the likelihood that blacknose dace are more acid-sensitive than brook char, blacknose dace densities did not show a similar response to deteriorating water quality, but probably were a function of specific features of the individual habitat units in which they lived. Even more effort has concentrated on the physical habitat relationships observed in stream fish communities (Matthews and Heins 1987; Meehan 1991; and Kohler and Hubert 1993). Gagen (1991) discussed the need to simultaneously consider effects due to habitat heterogeneity and chemical variability on stream fish communities. He further expressed concern that studying the above effects independently, or limiting the focus of studies to game species alone has led to an underestimate of the impacts of acidic precipitation in affected watersheds. We could not directly link species-specific differences in response to environmental conditions within a watershed to acidic conditions. But we did identify differences between species after we established linkages among population dynamics, habitat complexity, and water quality.

Research incorporating additional abiotic and biotic factors affecting populations in acid-sensitive systems would further our understanding of stream ecosystem dynamics and the potential for watershed restoration. Relations between food acquisition and utilization in acidic waters by fish have received inadequate attention (Wootton 1992). Information on density-dependent compensatory mechanisms at the population level that include changes in competitive and predatory interactions is still lacking (Gunn 1986; Charles 1991). Investigations of biotic interactions like competition and predation must include the entire fish taxocene within affected streams to provide ecological relevance. Considering the immense scale of the acidic deposition problem and the potential impacts on aquatic resources, future efforts at modeling changes in stream fish communities will profit from incorporating both habitat complexity and water quality into any analyses of community responses.

References

Adams, S. M. 1990. Status and use of biological indicators for evaluating the effects of stress on fish. American Fisheries Society Symposium 8:1-8.

Altshuller, A. P., and R. A. Linthurst. 1984. The Acidic Deposition Phenomenon and Its Effects: Critical Assessment Review Papers. EPA/600/8-83/016BF. U.S. Environmental Protection Agency, Washington, D.C.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 62-73 *In* N. B. Armantrout editor. Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division, American Fisheries Society, Portland, Oregon.

Charles, D. F., editor. 1991. Acidic Deposition and Aquatic Ecosystems. Springer-Verlag, New York, New York.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. Dept. of Agr., Forest Service, Southeastern Forest Experimental Station, Asheville, North Carolina.

Gagen, C. J. 1991. Direct effects of acidic runoff episodes on the distribution and abundance of fishes in streams of the Northern Appalachian Plateau. Ph.D. diss., The Pennsylvania State University, University Park, Pennsylvania.

Galloway, J. N., and E. B. Cowling. 1978. The effects of precipitation on aquatic and terrestrial ecosystems-a proposed precipitation chemistry network. Journal of the Air Pollution Control Association 28:229-235.

Gauch, H. G. Jr. 1982. Noise reduction by eigenvector ordinations. Ecology 63:1643-1649.

Gibbons, J. R. H., and J. H. Gee. 1972. Ecological segregation between longnose and blacknose dace (genus *Rhinichthys*) in the Mink River, Manitoba. Journal of Fisheries Research Board of Canada 29:1245-1252.

Gunn, J. M. 1986. Behavior and ecology of salmonid fishes exposed to episodic pH depressions. Environmental Biology of Fishes 12:241-252.

Haines, T. A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: A review. Transactions of the American Fisheries Society 110:669-707.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Science 45:834-844.

Jenkins, R. E., and N. M. Burkhead. 1993. Freshwater fishes of Virginia. American Fisheries Society, Bethesda, Maryland.

Johnson, D. W., H. A. Simonin, J. R. Colquhoun, and F. F. Flack. 1987. In situ toxicity tests of fishes in acidic waters. Biogeochemistry 3:181-208.

Kohler, C. C., and W. A. Hubert, editors. 1993. Inland fisheries management in North America. American Fisheries Society, Bethesda, Maryland.

Lennon, R. E. 1961. The trout fishery in Shenandoah National Park. U.S. Fish and Wildlife Service Special Scientific Report-Fisheries No. 395.

Matthews, W. J., and D. C. Heins, editors. 1987. Community and Evolutionary Ecology of North American Stream Fishes. University of Oklahoma Press, Norman, Oklahoma.

Meehan, W. R., editor. 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19, Bethesda, Maryland.

Munson, R. K., S. A. Gherini, M. M. Lang, L. E. Gomez, C. W. Chen, R. A. Goldstein, and D. R. Knauer. 1987. ILWAS model applications: Response of various surface waters to deposition acidity. Pages 301-308 *In* R. Perry, R. M. Harrison, J. N. B. Bell, and J. N. Lester editors. Acid Rain: Scientific and Technical Advances. Selper Ltd., Ealing, London.

National Academy of Sciences. 1986. Acid Deposition Long-Term Trends. National Academy Press, Washington, D.C.

Neves, R. J., and G. B. Pardue. 1983. Abundance and production of fishes in a small appalachian stream. Transactions of the American Fisheries Society 112:21-26.

Schindler, D. W. 1987. Detecting ecosystem responses to anthropogenic stress. Canadian Journal of Fisheries and Aquatic Science 446:6-25.

Schwartz, F. J. 1958. The breeding behavior of the southern blacknose dace, *Rhinichthys atratulus obtusus* Agassiz. Copeia 1958:141-143.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184.

Trial, J. G., J. G. Stanley, M. Batcheller, G. Gebhart, O. E. Maughan, and P. C. Nelson. 1983. Habitat suitability information: blacknose dace. U.S. Fish and Wildlife Service Biological Services Program FWS-OBS-82/10.41.

Webb, J. R., B. J. Cosby, J. N. Galloway, and G. M. Hornberger. 1989. Acidification of native brook trout streams in Virginia. Water Resources Research 25:1367-1377.

Webb, J. R., F. A. Deviney, J. N. Galloway, C. A. Rinehart, P. A. Thompson, and S. Wilson. 1994. The acid-base status of native brook trout streams in the mountains of Virginia. Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia.

Wootton, R. J. 1992. Ecology of Teleost Fishes. Chapman & Hall, London, England.

Zippen, C. 1958. The removal method of population estimation. Journal of Wildlife Management. 22:82-90.

Table 5A-1. Ranges of water quality variables from summer 1993 synoptic survey of three streams in Shenandoah National Park, Virginia.

Stream	Variable	Minimum	Maximum
Paine Run	alkalinity (µeq/L)	-13.1	20.3
	pH	4.86	6.17
	calcium (mg/L)	18.064	87.076
Staunton River	alkalinity (µeq/L)	60	106.2
	pH	6.78	6.94
	calcium (mg/L)	52.645	73.004
Piney River	alkalinity (µeq/L)	46.2	283.5
	pH	6.05	6.94
	calcium (mg/L)	32.934	172.704

Table 5A-2. Summary of stream length and numbers of habitat units surveyed on Paine Run, Staunton River, and Piney River, Shenandoah National Park, Virginia, May through June 1993.

Stream section	Length (m)	Pools	Riffles
Paine Run (main branch)	6,411.80	256	221
Lefthand Hollow	2,250.00	84	79
Chimney Rock	425.80	35	33
Horsehead Overlook	1,329.90	78	69
Staunton River (main branch)	6,435.70	321	264
Wilson Run	1,993.00	57	58
McDaniel Hollow	1,212.30	21	20
Garth Spring Run	709.20	0	1
Piney River (main branch)	8,861.80	310	285
Right Fork	2,211.90	3	4

Table 5A-3. Basinwide visual estimates of total surface area (m^2) of each habitat type in three streams with different acid neutralizing capacity (ANC) of the Shenandoah National Park, Virginia, from surveys completed in June 1993. 95% confidence interval in parentheses.

Stream	Reach	Habitat area(m^2) Pool	Riffle	Total
Paine Run[a.]	Main branch	10,358	14,533	24,892
		(+/-461)	(+/-574)	(+/-732)
	Lefthand Hollow	1,154	3,422	4,576
		(+/-79)	(+/-164)	(+/-186)
	Chimney Rock	185	440	625
		(+/-17)	(+/-138)	(+/-140)
	Horsehead Mtn.	772	2,080	2,852
	Overlook	(+/-61)	(+/-444)	(+/-449)
Staunton River[a.]	Main branch	8,967	16,540	25,506
		(+/-424)	(+/-676)	(+/-796)
	Wilson Run	545	5,022	5,567
		(+/-46)	(+/-468)	(+/-471)
	Garth Springs Run[b.]	N/A	N/A	N/A
	McDaniel Hollow	164	1,554	1,718
		(+/-48)	(+/-115)	(+/-115)
Piney River[a.]	Main branch	8,464	19,592	28,056
		(+/-442)	(+/-1,120)	(+/-1,193)
	Right Fork[c.]	20	1,382	1,402

a. Paine Run = low ANC; Staunton River = moderate ANC; Piney River = high ANC
b. Garth Springs Run consisted of entirely marginal habitat with an average depth of less than 5 centimeters from its confluence with the main branch of Staunton River to its source.
c. Estimates for the Right Fork of Piney River used calibration ratios from the main branch survey; lack of suitable habitat resulted in insufficient sample size to calculate confidence limits.

Table 5A-4. Basinwide visual estimates of brook char (*Salvelinus fontinalis*) populations in three streams with different acid neutralizing capacity (ANC) of the Shenandoah National Park, Virginia, from surveys completed August 1993. 95% confidence interval in parentheses.

Stream	Reach	Abundance estimate	
		Pool	Riffle
Paine Run[a.]	Main branch	1,355	642
		(+/-457)	(+/-565)
	Lefthand Hollow[b.]	25	0
		(+/-63)	(N/A)
	Chimney Rock[b.]	0	0
		(N/A)	(N/A)
	Horsehead Mtn.	67	30
	Overlook	(+/-187)	(+/-81)
Staunton River[a.]	Main branch	2,266	1,200
		(+/-729)	(+/-1,145)
	Wilson Run	65	48
		(+/-189)	(+/-62)
	Garth Springs Run[b.]	0	0
		(N/A)	(N/A)
	McDaniel Hollow[b.]	0	0
		(N/A)	(N/A)
Piney River[a.]	Main branch	3,451	2,152
		(+/-1,451)	(+/-1,633)
	Right Fork[b.]	0	0
		(N/A)	(N/A)

a. Paine Run = low ANC; Staunton River = moderate ANC; Piney River = high ANC
b. No brook char were seen by divers or captured by electrofishing.

Table 5A-5. Basinwide visual estimates of blacknose dace (*Rhinichthys atratulus*) populations in three streams with different acid neutralizing capacity (ANC) of the Shenandoah National Park, Virginia, from surveys completed August 1993. 95% confidence interval in parentheses.

Stream	Reach	Abundance estimate: Pool	Abundance estimate: Riffle
Paine Run[a.]	Main branch	2,404	1,245
		(+/-746)	(+/-2,444)
	Lefthand Hollow	901	501
		(+/-533)	(+/-850)
	Chimney Rock[b.]	0	0
		(N/A)	(N/A)
	Horsehead Mtn. Overlook[b.]	0	0
		(N/A)	(N/A)
Staunton River[a.]	Main branch	501	147
		(+/-932)	(+/-449)
	Wilson Run[b.]	0	0
		(N/A)	(N/A)
	Garth Springs Run[b.]	0	0
		(N/A)	(N/A)
	McDaniel Hollow[b.]	0	0
		(N/A)	(N/A)
Piney River[a.]	Main branch	1,842	821
		(+/-1,129)	(+/-400)
	Right Fork[b.]	0	0
		(N/A)	(N/A)

a. Paine Run = low ANC; Staunton River = moderate ANC; Piney River = high ANC
b. No blacknose dace were seen by divers or captured by electrofishing.

Table 5A-6. ANOVA on ranks table of probabilities for effects of dependent variables among Paine Run (low ANC), Staunton River (moderate ANC), and Piney River (high ANC). Tests were conducted individually by habitat unit type.

Unit type	Characteristic	Significance level
pool	density of BKT[a.]	P=0.0002
	density of BND[a.]	P<0.0001
	area	P=0.6560
	maximum depth	P<0.0001
	average depth	P<0.0001
	primary substrate	P<0.0001
	secondary substrate	P=0.9713
	LWD[b.] loading	P=0.5702
	alkalinity	P<0.0001
	pH	P<0.0001
	calcium	P<0.0001
riffle	density of BKT[a.]	P=0.1645
	density of BND[a.]	P=0.1584
	area	P=0.4758
	maximum depth	P=0.0002
	average depth	P=0.0004
	primary substrate	P=0.0044
	secondary substrate	P=0.0299
	LWD[b.] loading	P=0.0923
	alkalinity	P<0.0001
	pH	P<0.0001
	calcium	P<0.0001

a. BKT = brook char; BND = blacknose dace
b. LWD = large woody debris

Table 5A-7. Variable loadings, eigenvalues, and variance explained in principal components analysis on habitat characteristics measured in pools occupied by brook char and blacknose dace among three streams with different acid neutralizing capacity in Shenandoah National Park, Virginia.

	Brook char		Blacknose dace	
Variable	PC1	PC2	PC1	PC2
area (m^2)	0.282	0.120	-0.314	-0.503
maximum depth (cm)	0.668	0.044	-0.631	-0.086
average depth (cm)	0.658	-0.027	-0.621	-0.036
primary substrate	-0.132	0.706	0.243	-0.672
secondary substrate	-0.152	-0.268	0.207	-0.021
LWD[a.]	-0.010	-0.643	-0.124	0.535
eigenvalue	2.060	1.227	2.217	1.266
proportion of variance	0.343	0.204	0.370	0.211
cumulative variance	0.343	0.548	0.370	0.580

a. LWD = large woody debris

Table 5A-8. Variable loadings, eigenvalues, and variance explained in principal components analysis on habitat characteristics and water quality variables measured in pools occupied by brook char and blacknose dace among three streams with different acid neutralizing capacity in Shenandoah National Park, Virginia.

	Brook char		Blacknose dace	
Variable	PC1	PC2	PC1	PC2
area (m^2)	-0.048	0.387	0.248	0.362
maximum depth (cm)	-0.389	0.499	-0.110	0.613
average depth (cm)	-0.350	0.525	-0.093	0.605
primary substrate	0.225	0.082	0.322	-0.181
secondary substrate	0.045	-0.141	-0.030	-0.206
LWD[a.]	0.026	0.017	0.004	0.113
alkalinity (µeq/L)	-0.485	-0.330	-0.525	-0.112
pH	-0.522	-0.104	-0.522	0.089
calcium (mg/L)	-0.403	-0.422	-0.516	-0.142
eigenvalue	3.054	1.795	3.241	2.271
proportion of variance	0.339	0.199	0.360	0.252
cumulative variance	0.339	0.539	0.360	0.612

a. LWD = large woody debris

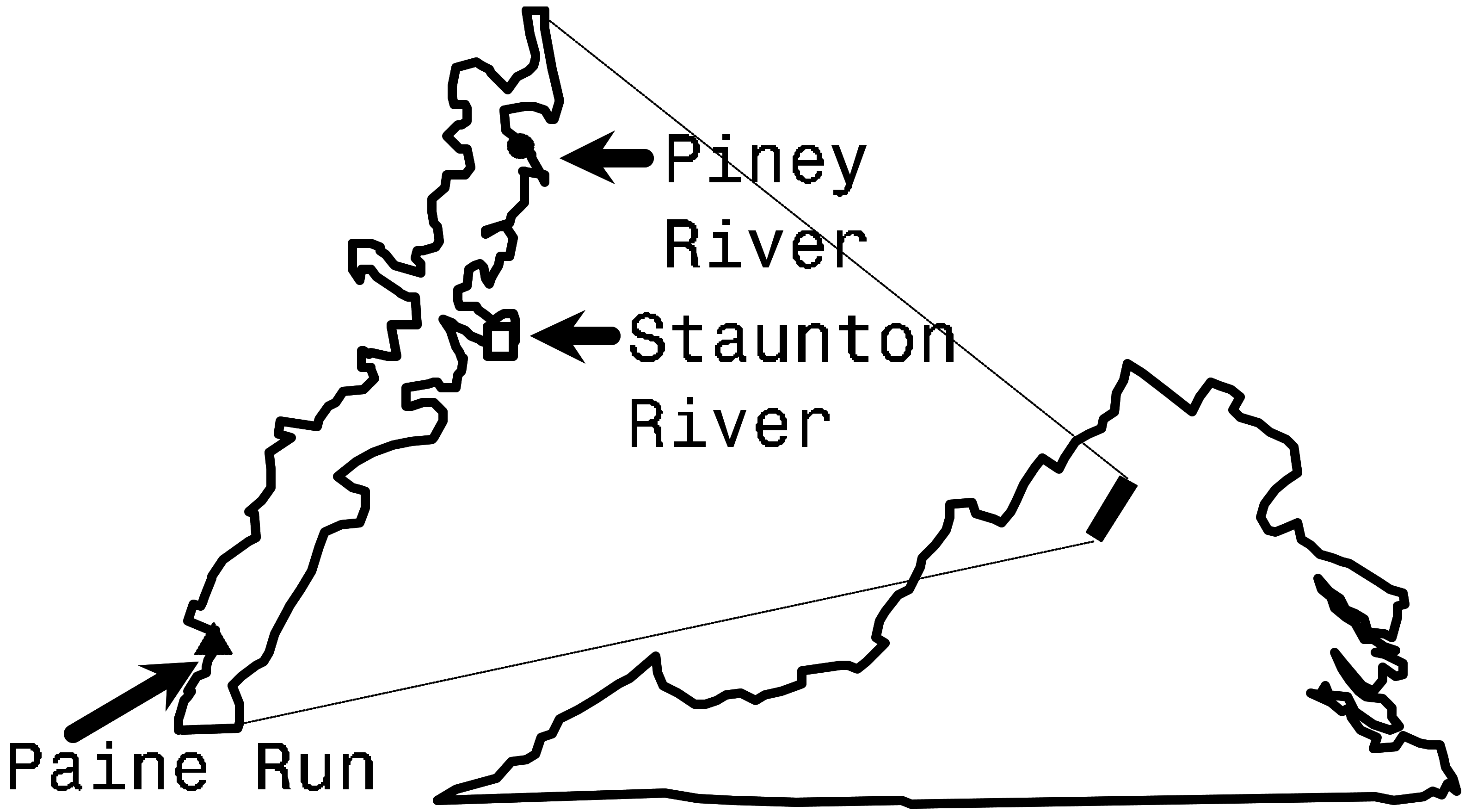

Figure 5A-1. Location of three study streams of different ANC in Shenandoah National Park, Virginia.

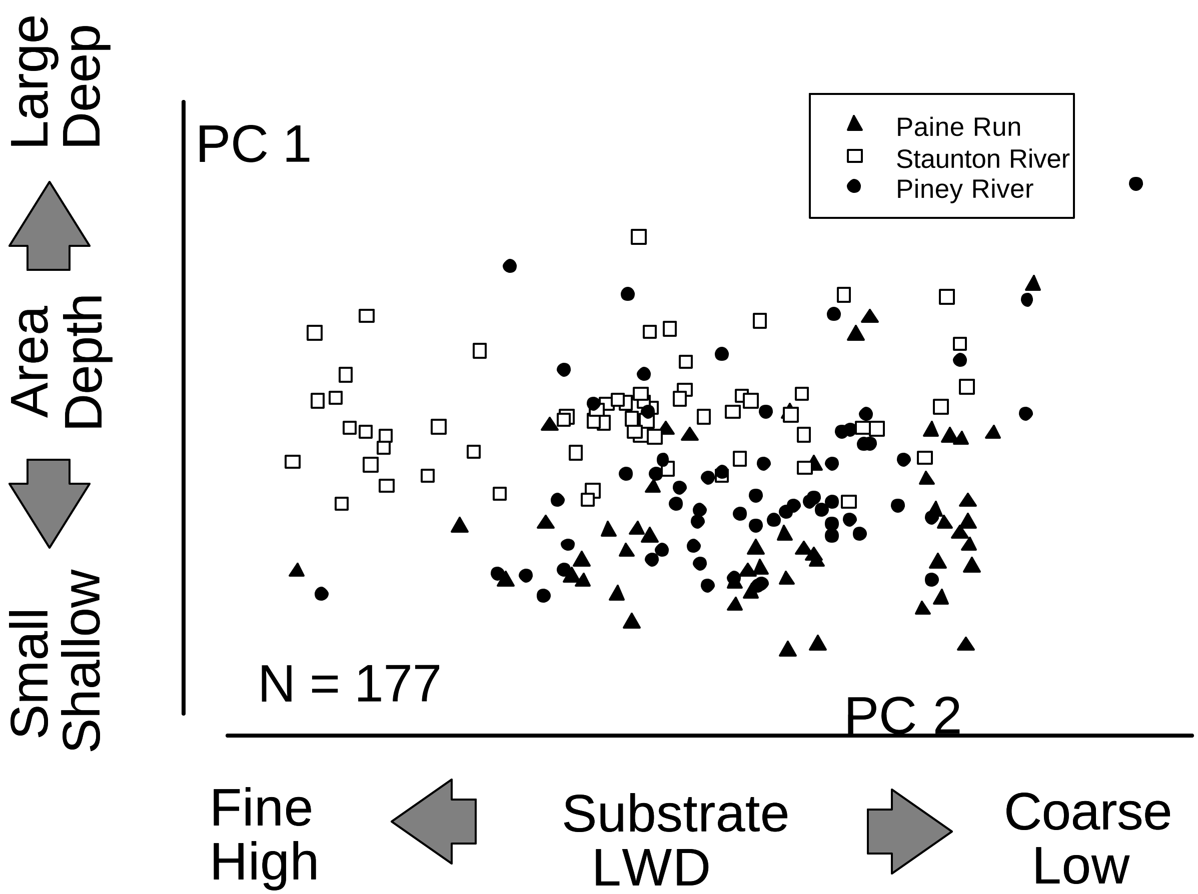

Figure 5A-2. Principal component scores for habitat variables measured in pools occupied by brook trout in three streams of different ANC in Shenandoah National Park, Virginia.

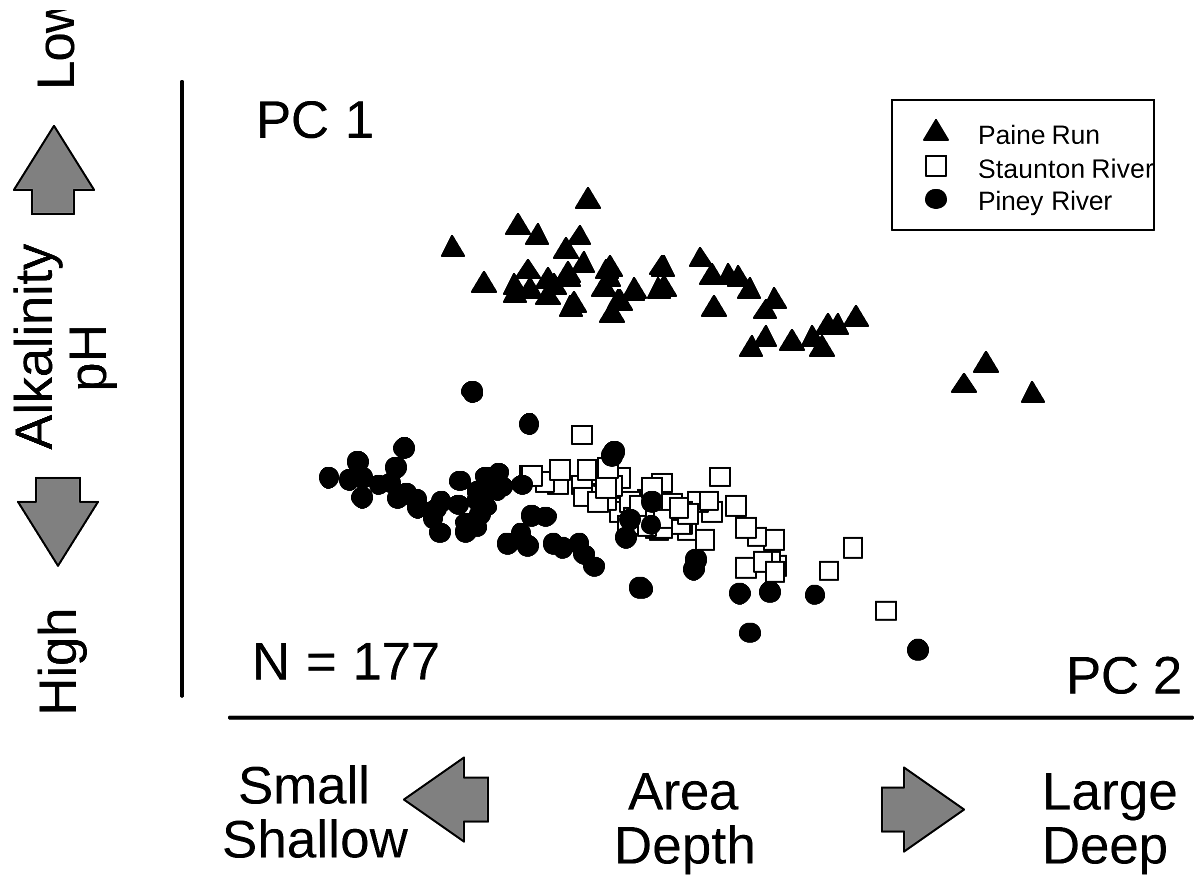

Figure 5A-3. Principal component scores for habitat and water quality variables measured in pools occupied by brook trout in three streams of different ANC in Shenandoah National Park, Virginia.

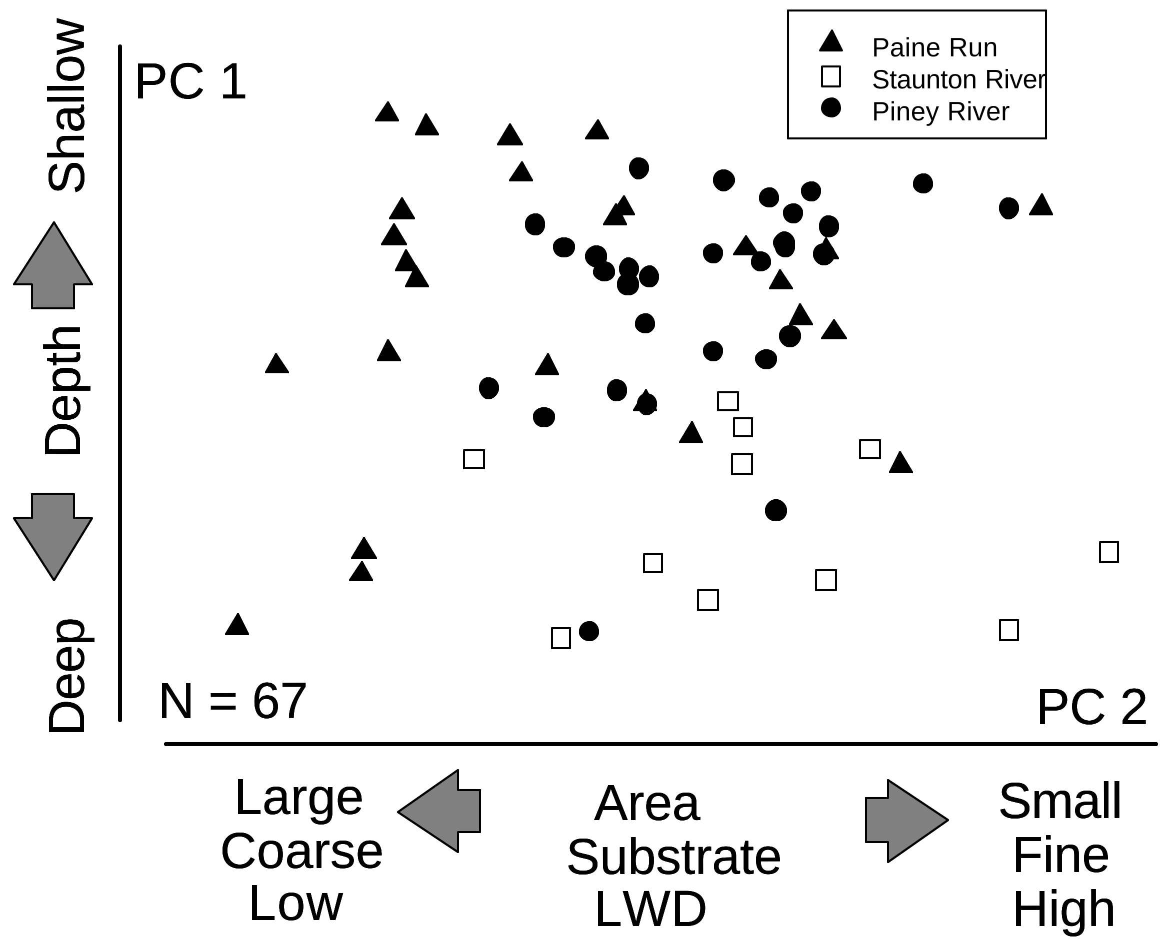

Figure 5A-4. Principal component scores for habitat variables measured in pools occupied by blacknose dace in three streams of different ANC in Shenandoah National Park, Virginia.

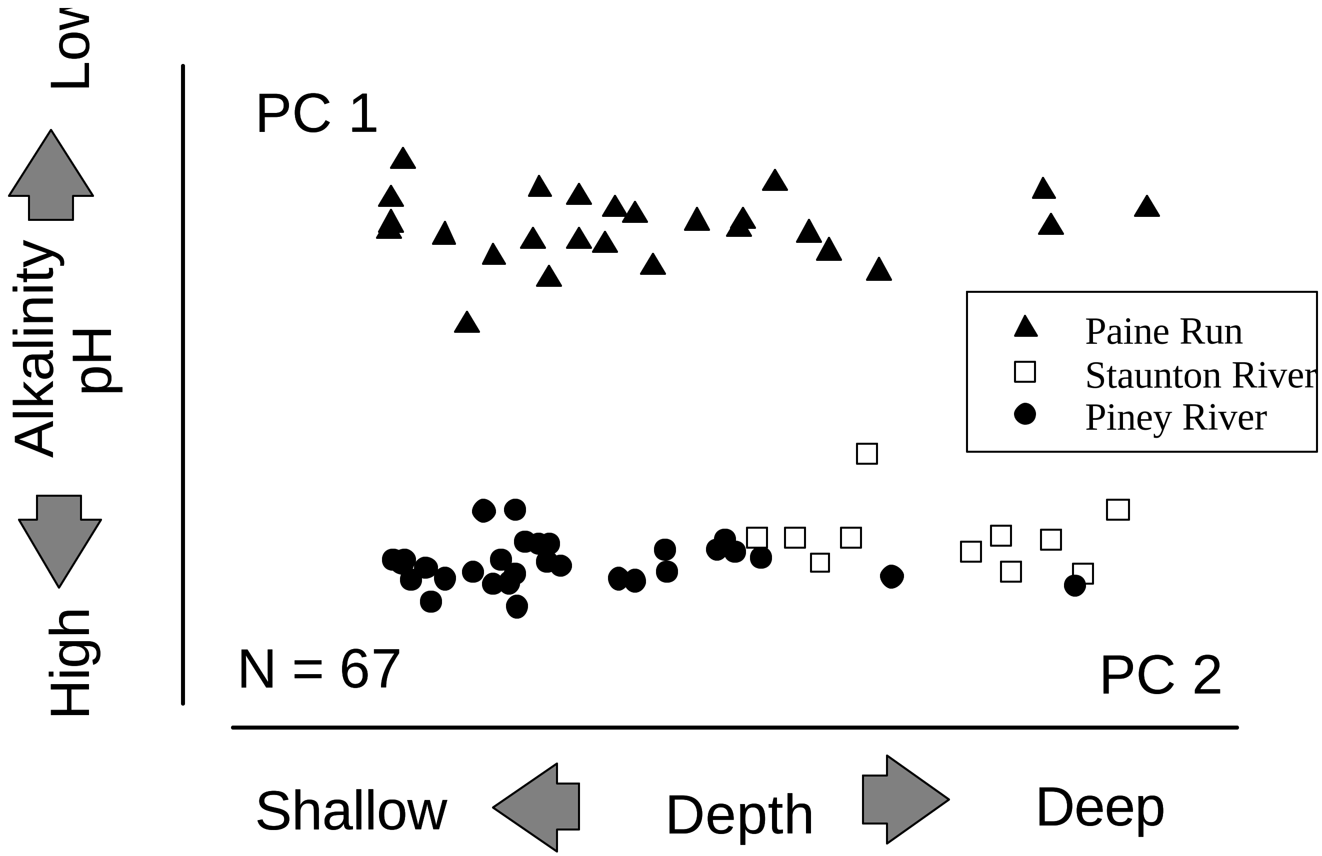

Figure 5A-5. Principal component scores for habitat and water quality variables measured in pools occupied by blacknose dace in three streams of different ANC in Shenandoah National Park, Virginia.

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Chapter 5B
Condition, Production, and Population Dynamics of Brook Char and Blacknose Dace in Acid-Sensitive Shenandoah National Park Watersheds

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Abstract

We used basinwide visual estimation techniques to sample brook char (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*) in three headwater streams of different acid neutralizing capacity (ANC) originating within Shenandoah National Park (SNP). We estimated fish density, mean weight, standing stock, growth, production, mortality, and condition factor among streams, habitat types, and sample periods to examine the relative performance of populations among streams and to determine the relationship between fish performance and water quality. Total density of brook char did not vary significantly through time but was highest in Piney River (high ANC) throughout the study. Total density of blacknose dace was highest in Paine Run (low ANC), intermediate in Piney River, and lowest in Staunton River (moderate ANC). The confidence intervals for annual production by brook char were: Paine Run = 24 to 26 kg/ha; Staunton River = 28 to 40 kg/ha; and Piney River = 48 to 77 kg/ha. Production by age 0+ fish in pools was greater than all other age/habitat designations. No difference in production existed among any other age/habitat designation. Annual production estimates for blacknose dace ranged from 0.3 to 2.0 kg/ha among streams. We were unable to detect any influence on production of blacknose dace. Median values for condition factor of brook char ranged from 0.92-0.99 and varied among streams, sampling periods, and age/habitat designations. The condition factor of brook char in Staunton River was higher than in either of the other streams. Generally condition factor was higher in riffles than in pools, and increased with fish age. Median

values of blacknose dace condition factor ranged from 0.85 to 1.14 and varied among streams, sampling periods, and habitat. Condition factors of blacknose dace in Piney River and Staunton River were similar, while both streams had higher condition factors than dace in Paine Run. Blacknose dace condition factor was higher in pools than in riffles.

We did not link known differences in ANC directly to population-level performance of brook char and blacknose dace, although on the basis of condition factor and mean weight, both species appeared to be doing best in Staunton River and worst in Paine Run. We suggest developing better age at length criteria, increased frequency of sampling, extension of sampling over multiple consecutive years, and inclusion of all fish species in all analyses to clarify the relationships in our conceptual model of fish production. Future research should be directed at comparing available energy resources in streams with different ANC, and at linking resource availability with temporal variation in water quality.

Introduction

The performance of individual organisms and the populations from which they come is strongly influenced by biotic and abiotic factors in their environment. Growth, production, and condition are especially useful for inferring the health and status of aquatic ecosystems (Weatherley 1972). One abiotic factor that has received relatively little attention is the effect of acidic water on patterns of energy acquisition and allocation in fish (Wootton 1992; but see Lemly and Smith 1985).

Haines (1981) reviewed the consequences of acidic precipitation for aquatic ecosystems, and discussed reductions in fish abundance, production, and growth attributable to acidic conditions. Other reviews have discussed the desirability of examining fish production to assess the dynamic state of a population or community (Waters 1977, Chapman 1978). Most production studies have focused on game species, ignoring contributions to total production or performance characteristics of non-game species in an assemblage, and few studies have attempted to compare production among reaches within a stream or among basins within a region, although there are a few notable exceptions (Chapman 1965, Hunt 1974, Egglishaw and Shackley 1977, Neves and Pardue 1983, and Newman and Waters 1989). Chapman (1978) theorized that a stratified random sample over time might reveal differences in factors responsible for production among regions, waters, and sample periods. This type of analysis could also be used to compare the relative performance characteristics of fish populations from watersheds that differed significantly in some factor such as water quality. The condition factors of fish of the same species from different watersheds could similarly be compared, provided samples were representative of the populations in each watershed (Weatherley 1972). The relationship between length and weight expressed by condition factor provides an index frequently used to quantify the state of well-being of a fish (Wootton 1992). Comparisons of condition factors among populations and watersheds should permit inferences concerning performance of populations and health of ecosystems relative to differences in water quality.

In this study we compared growth, production, population dynamics, and condition of brook char (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*) in three headwater streams originating within Shenandoah National Park (SNP). Although species richness ranged from 3 to 7 species, only brook char and blacknose dace were found in all three watersheds. These watersheds differed significantly in the acid neutralizing capacity (ANC) of their soils (Chapter 1), resulting in differences in the ability to buffer the adverse effects of acidic deposition. Our primary objective was to examine the relative performance of populations among these streams, and determine the relationship between fish performance and water quality. We sampled brook char and blacknose dace in all three watersheds to examine fish density, mean weight, standing stock, growth, production, mortality, and condition factor among streams, habitat types, and sample periods.

Methods

Fish Population Characteristics

We evaluated fish performance characteristics over three sampling periods spanning two consecutive years as influenced by ANC and within-basin variability of physical habitat. Sampling was conducted in the spring and fall of 1993 and 1994 (May and October, respectively), in each of three SNP streams that ranged in ANC from low to high: Paine Run (low ANC), Staunton River (moderate ANC), and Piney River (high ANC). Fish populations were estimated using the Hankin and Reeves (1988) two-stage basin-wide visual estimation technique (BVET)(Dolloff et al. 1993). Diver's fish identifications and fish counts were verified and calibrated by multiple-pass (at least 3) removal techniques (Zippen 1958). We used a gasoline-powered backpack electrofisher (700-volt AC) to capture fish, which were identified, measured for total length (to nearest 1 mm), and weighed (0.1 g) before being returned to the stream. Diver counts of fish number per unit of habitat area (density) were averaged by habitat type in each reach to obtain estimates of density (fish/100m^2). Habitat area estimates by habitat unit types were made in a separate but related study (Chapter 5A); Paine Run - 24,892 +/- 818 m^2; Staunton River - 25,506 +/- 875 m^2; and, Piney River - 28,056 +/-

1,194 m^2. All analyses were limited to habitat available to fish in the main stem of each stream, and habitat types were limited to pools and riffles following descriptions by Bisson et al. (1982).

Separate abundance estimates were made by habitat type for brook char and blacknose dace. Brook char were further divided into two age groups on the basis of length-frequency histograms from each sampling period: (1) age 0+, and (2) age 1+ and older (henceforth simply referred to as age 1+). Aging of individuals from each sampling period using scales or otoliths would have provided clearer separation of older age groups. We initially intended to use the standardized length at age criteria, developed from ageing scales of SNP brook char, which is currently applied to all char waters in the Park by management officials (J. Atkinson personal communication). However, after comparing the SNP standards with length-frequency histograms from each sample, the two age groups designated were the finest level of resolution achievable in agreement with the Parks previously developed criteria. Blacknose dace populations were considered as a whole, because we were unable to consistently separate year classes on the basis of length-frequency histograms.

Production rates were calculated by the instantaneous growth rate method of Ricker (1946) and Allen (1949):

$$P = GB_M$$

where P = production in g/m^2 wet weight for the interval between estimates;
G = instantaneous growth rate for the interval;
B_M = mean standing stock in g/m^2 for the interval;

and:

$$G = \ln(W_f / W_i)$$

where W_i = initial wet weight (g) at the beginning of an interval;
W_f = final wet weight (g) at the end of an interval;

and:

$$B_M = B_0 \, (e^{G-Z}-1) / (G-Z)$$

where B_0 = standing stock in g/m^2 at beginning of interval;

and:

$$Z = -\ln (N_f / N_i)$$

Z = instantaneous mortality rate for the interval;
N_f = fish abundance at the end of the interval;
N_i = fish abundance at the beginning of the interval.

When an age group or species disappeared from a habitat type during an interval, production was zero. The above procedure resulted in estimates of production by age group, for each species, in each habitat type, for all intervals. Annual production for each species was the sum of production for all age groups designated in each habitat unit type and all intervals, from May 1993 to May 1994 (e.g., the first two intervals of the three sampled). Contributions to annual production by age 0+ fish from the time of egg deposition to the time of sampling in the spring of 1994 were presented as a range. For the lower end of the range, we used the standing stock of age 0+ fish at the time of the May 1994 sample as a minimum estimate of production prior to that sample. Although this did not take into account growth and mortality from egg deposition to the spring sample, it was preferable to assuming production was zero in the interval since growth is known to be especially rapid during these early life history stages.

Several additional assumptions were necessary to estimate the upper end of the range; we assumed a 1:1 sex ratio in all three streams, that all reproductive-sized females (e.g., age 1+) spawned during the year, and that all eggs from each female were successfully fertilized. We further assumed the average weight of a fertilized egg to be 0.1 gm (Carlander 1969, Power 1980). Total length of all age 1+ fish captured ranged from 158 to 277 mm, with an average total length of 215 mm. Average fecundity of a female brook char with this total length in in-fertile Pennsylvania streams was 349 eggs/female (Carlander 1969), and 300 eggs/female in several mid-western streams (Power 1980). We assumed the fecundity of females in this study to be 325 eggs/female (e.g., the average of fecundities reported above). We estimated biomass, growth, mortality, and production from egg deposition to the time of our spring 1994 sample by dividing the abundance estimates of age 1+ fish from the previous fall sample (e.g., October 1993) in half, and multiplying 325 eggs/female by 0.1 grams.

The combination of procedures allowed us to construct a confidence interval containing the “true” contribution to annual production by age 0+ fish. All statistical analyses were conducted using the lower and upper limits independently, and were considered as a range in the reporting of results. After calculating production (and associated parameters) by each cohort for the spring 1993 to fall 1993 interval, we calculated overwinter production for age 1+ fish by combining abundance, mean length, and mean weight data for both age 0+ fish and age 1+ fish at the time of the fall 1993 sample, and comparing that data to the age 1+ cohort data the following spring. This was done because all fish observed during the fall 1993 survey recruited to the age 1+ and older cohort by the spring of 1994.

Condition factor (K) was calculated for each brook char and blacknose dace as:

$$K = (W / L^3)*10^5$$

where K = condition factor;

W = wet weight (g);

L^3 = cube of total length (mm).

The ratio of W to L^3 was multiplied by 10^5 to produce values near unity (Anderson and Gutreuter 1983).

Statistical analyses

We used Friedman's repeated measures analysis of variance (RM ANOVA) to assess differences in the estimated parameters among streams, sampling period or interval, and a class that combined habitat type with age of fish for both species common to all three streams (referred to as the age/habitat factor for the remainder of this text). The age/habitat factor had six levels defined as follows: (1) age 0+ brook char in pools; (2) age 1+ brook char in pools; (3) age 0+ brook char in riffles; (4) age 1+ brook char in riffles; (5) blacknose dace in pools; and (6) blacknose dace in riffles. Parameters included in the analyses were density (fish/100m^2), average weight (g), mean standing stock during an interval (g/m^2), and production (g/m^2/interval). When a parameter was identified as significant for any factor ($P<0.05$), we used the Student-Newman-Keuls test (SNK) to isolate the group(s) that differed from the others. We used the Mann-Whitney Rank Sum test to assess differences in the parameters median values for age/habitat designations for blacknose dace. Examination of RM ANOVA or Mann-Whitney results, the multiple comparisons (SNK) results, and the parameter medians allowed us to determine the relative structure of significant differences among streams, sample periods, or age/habitat designations. Because negative values of growth or production indicate a populations response to degrading environmental conditions, negative values were considered in the RM ANOVAs described above. We used Kruskal-Wallis nonparametric ANOVA to analyze condition factors for brook char and blacknose dace both withn and among streams, sample periods and age/habitat designations. Once again, because the age/habitat factor for blacknose dace only had two levels the Mann-Whitney Rank Sum test was used to assess differences in median values. We used Dunn's test for multiple comparisons when the sample sizes in the treatment groups differed (e.g. when different numbers of each species were captured in each stream at each sampling period).

We used Spearman's rank order correlation coefficients (r_S) to examine the relationship between mean density and mean condition factor of brook char and blacknose dace during each sampling period in all three streams (twelve pairs for each correlation).

Results

Brook Char Density

Total density of brook char was variable among sample periods and streams, but generally remained highest in Piney River (high ANC) throughout the study (Figure 5B-1). Total density of brook char did not vary significantly through time among the streams (Table 5B-1 and 5B-2). However, during the spring of 1993 we found significant differences in density in pool habitat among streams (Chapter 5A). Differences in the median values of brook char densities among sample periods were not great enough to exclude the possibility that those differences were due to random sampling variability (Tables 5B-1 and 5B-2). We found significant differences in the median values of brook char densities among the age/habitat designations (Tables 5B-1 and 5B-2). Median values for density estimates of brook char ranged from 1 to 11 fish/100m^2 for the age/habitat designations (Tables 5B-3 and 5B-4). Densities of both cohorts were similar in pool and riffle habitat and densities of both cohorts pool habitat were greater than in riffle habitat (SNK, $P<0.05$).

Blacknose Dace Density

Total density of blacknose dace was also variable among sample periods and streams, but relative differences among streams remained constant through time. Density was highest in Paine Run (low ANC), intermediate in Piney River (high ANC), and lowest in Staunton River (moderate ANC) (Figure 5B-2). These observed differences in blacknose dace density were significant among streams (Table 5B-5). The median values of blacknose dace density among streams ranged from 2 to 18 fish/100m^2 (Table 5B-6). Blacknose dace density was highest in Paine Run (low ANC), lowest in Staunton River (moderate ANC), and intermediate in Piney River (SNK, $P<0.05$). Differences in the median values of blacknose dace densities among sample periods were not great enough to exclude the possibility that those differences were due to random sampling variability (Table 5B-5). Blacknose dace densities did vary significantly between pool and riffle habitat (Mann-Whitney, $P<0.0001$). Median densities in the two habitat types ranged from 1 to 19 fish/100m^2, and was higher in pools than in riffles (Table 5B-6).

Brook Char Standing Stock

The mean standing stock of brook char (g/m^2) was variable among streams, sampling intervals, and age/habitat designations. The median values for the average brook char standing stock differed significantly among sampling intervals and age/habitat designations when using the lower estimate of age 0+ production from egg deposition to the May 1994 sample (Table 5B-1). The median values for average biomass ranged from 28.6 to 179.0 $g/100m^2$ among sampling intervals (Table 5B-3). Average biomass was highest during the spring to fall 1994 interval, and significantly greater than either of the other two intervals (SNK, $P<0.05$). There was no difference in average biomass between the spring and fall of 1993 or fall 1993 and spring 1994. The median values for average biomass ranged from 9.0 to 388.4 $g/100m^2$ among age/habitat designations (Table 5B-3). The average biomass of age 1+ fish in pool habitat was higher than all other age/habitat designations (SNK, $P<0.05$). Average biomass among all other age/habitat designations were similar. Differences in the median values of brook char mean standing stock among streams were not great enough to exclude the possibility that the differences were due to random sampling variability when using the lower estimates of age 0+ contribution to annual production (Table 5B-1).

The median values for brook char standing stock varied significantly only among the age/habitat designations when using the upper estimate of age 0+ production from egg deposition to the May 1994 sample (Table 5B-2). Median values for these estimates of average biomass ranged from 12.0 to 388.4 g/m^2 and are presented in Table 5B-4. Again, the average biomass of age 1+ fish in pool habitat was greater than all others (SNK, $P<0.05$). Average biomass of age 0+ fish in pools also was higher than average biomass of all fish in riffle habitat (SNK, $P<0.05$). No difference was observed in average biomass between age 0+ fish and age 1+ fish in riffles. Differences in the median values of brook char mean standing stock were not great enough to exclude the possibility that those differences were due to random sampling variability among streams or sampling intervals when using the upper estimates of age 0+ contribution to annual production (Table 5B-2).

Blacknose Dace Standing Stock

Mean standing stock of blacknose dace (g/m^2) was variable among streams, sampling intervals, and habitat types. The median values for blacknose dace mean standing stock differed significantly among streams and age/habitat designations (Table 5B-5). Median values for these estimates of average biomass ranged from 5.7 to 40.0 $g/100m^2$ among streams, and from 1.2 to 43.4 $g/100m^2$ between riffle and pool habitat

(Table 5B-6). Average biomass of blacknose dace was similar in Paine Run (low ANC) and Piney River (high ANC) but lower in Staunton River (moderate ANC) (SNK, P<0.05). Average biomass in pool habitat also was greater than in riffles (Mann-Whitney, P=0.0027). Differences in the median values of the mean standing stock of blacknose dace were not great enough to exclude the possibility that those differences were due to random sampling variability among sampling intervals (Table 5B-5).

Brook Char Mean Weight

The mean weight of brook char was variable among streams, sample periods, and age/habitat designations. Mean weight was significantly different among streams and age/habitat designations (Table 5B-1 and 5B-2). Median values for mean weight ranged from 4.0 to 15.6 grams among streams, and from 3.3 to 49.8 grams among age/habitat designations (Table 5B-3 and 5B-4). Mean weight of brook char was similar in Piney River (high ANC) and Staunton River (moderate ANC); brook char in Paine Run (low ANC) were smaller than in the other streams (SNK, P<0.05). Mean weight of age 1+ fish in pools was greater than all other age/habitat designations (SNK, P<0.05). Mean weights of all age 0+ fish were similar.

Blacknose Dace Mean Weight

The mean weight of blacknose dace was variable among streams, sample periods, and age/habitat designations. Mean weight differed significantly among streams (Table 5B-5). Median values for mean weight ranged from 2.0 to 4.9 grams among streams (Table 5B-6). Mean weight of blacknose dace was similar between Piney River (high ANC) and Staunton River (moderate ANC); mean weight of blacknose dace in Paine Run was lower than in the other streams (SNK, P<0.05).

These analyses suggest that mean weight for both species was determined more by spatial (habitat) variability than differences across sampling periods. Differences in the size of brook char were determined by fish age, habitat, and stream of origin. Blacknose dace size also was strongly influenced by spatial variability among streams.

Brook Char Production

Production by brook char was variable among streams sample intervals, and age/habitat designations. Differences in the median values of production among the three factors were not significant when using the lower estimates of age 0+ contribution to the annual totals (Table 5B-1). Median values of production did differ significantly among sampling intervals and age/habitat designations when using the upper estimates of age 0+ contribution to the annual totals (Table 5B-2). Median values of production ranged from 4.1 to 106.1 $g/100m^2$ among sampling intervals (Table 5B-4). Production was greater during the fall 1993 to spring 1994 interval than during any other time (SNK, $P<0.05$). Production also was greater during the spring 1993 to fall 1993 interval than during the same interval in 1994 (SNK, $P<0.05$). Median values of brook char production ranged from -41.0 to 176 $g/100m^2$ among age/habitat designations (Table 5B-4). Production by age 0+ fish in pools was greater than all other age/habitat designations (SNK, $P<0.05$). No difference in production existed among any other age/habitat designation.

The confidence intervals for annual production by brook char, using a lower and upper estimate of the contribution by age 0+ fish to the annual totals, were: Paine Run (low ANC) = 24 to 26 kg/ha; Staunton River (moderate ANC) = 28 to 40 kg/ha; and Piney River (high ANC) = 48 to 77 kg/ha (Figure 5B-3). When considering either scenario independently (e.g., lower and upper estimates of the contribution to annual production by age 0+ fish), production by brook char did not differ significantly among streams. However, brook char production appeared to be influenced by spatial (habitat) variability, fish age, and temporal variability when using the upper estimates of production by age 0+ fish.

Blacknose Dace Production

Production by blacknose dace was variable among streams, sample intervals, and age/habitat designations. Differences in the median values of blacknose dace production among all factors were not great enough to exclude the possibility that those differences were due to random sampling error (Table 5B-5). Annual production estimates ranged from 0.3 to 2 kg/ha among streams (Figure 5B-4). We were unable to detect any influence on production of blacknose dace.

Brook Char Production to Biomass Ratios (P/B)

Annual *P/B* ratios ranged from 0.2 to 0.4 in Paine Run (low ANC), from 0.5 to 0.6 in Staunton River (moderate ANC), and from 0.2 to 0.4 in Piney River (high ANC) (Table 5B-7). These ranges were calculated using the lower and upper estimates of age 0+ production from the time of egg deposition to the time of the spring sample in 1994. When considering the lower estimates of age 0+ production, Paine Run had the highest ratio, while Staunton River and Piney River were similar (Table 5B-7). When considering the higher estimates of age 0+ production, Piney River had the highest ratio, Paine Run was lowest again, and

Staunton River was intermediate (Table 5B-7). *P/B* ratios for age 1+ fish were highest in Staunton River, lowest in Paine Run, and intermediate in Piney River (Table 5B-7).

Blacknose Dace P/ ratios

Annual *P/* ratios ranged from 0.1 to 0.3 (Table 5B-8). In pools, Piney River (high ANC) had the highest ratio, Paine Run (low ANC) had the lowest, and Staunton River (moderate ANC) was intermediate (Table 5B-8). Piney River had a higher ratio in riffle habitat than Paine Run, while Staunton River had no measurable production of blacknose dace in riffles (Table 5B-8).

Brook Char Condition Factor

Median values for condition factor of brook char ranged from 0.92-0.99 (Table 5B-9) and varied among streams, sampling periods, and age/habitat designations (Figure 5B-5 through 5B-7) (ANOVA on ranks, P<0.0001). The condition factor of brook char in Staunton River (moderate ANC) was higher than in either of the other streams (P<0.05); condition factor of brook char in Paine Run and Piney River was similar. Condition factor ranged from 0.88 to 1.08 (Table 5B-9) and differed among sampling periods (ANOVA on ranks, P<0.0001). Condition factor of brook char during the spring 1994 sample was higher than at any other sample period (P<0.05). Condition factor during the spring 1993 sample was higher than during the fall 1993 sample (P<0.05), but was similar to condition during the fall 1994 sample. Condition factor during the fall 1994 sample was also higher than during the fall 1993 sample (P<0.05). Generally brook char condition factor was higher in the spring than in the fall, and was higher during the second year than the first. Median values of condition factor differed among age/habitat designations (ANOVA on ranks, P<0.0001) and ranged from 0.90 to 1.03 (Table 5B-9).

Condition factor of age 1+ fish in riffle habitat was higher than all other age/habitat designations (P<0.05). Condition factor of age 0+ fish in riffles was also higher than either age group in pools (P<0.05). The condition factor of age 0+ fish and age 1+ fish in pool habitat did not differ significantly. Generally condition factor was higher in riffles than in pools, and increased with the age of the fish.

Blacknose Dace Condition Factor

Median values of blacknose dace condition factor ranged from 0.85 to 1.14 (Table 5B-9) and varied among streams, sampling periods, and habitat (Figure 5B-8 through 5B-10)(ANOVA on ranks, P<0.0001).

Condition factors of blacknose dace in Piney River and Staunton River were similar, while both streams had higher condition factors than dace in Paine Run. Generally, blacknose dace condition factor was higher in the spring than in the fall, and was higher in 1994 than in 1993 (Mann-Whitney, P=0.0019). Blacknose dace condition factor was higher in pools than in riffles (Table 5B-9).

Relationship of Condition Factor and Density

Condition factor for both species was inversely related to density; Spearman's r_S was -0.62 (P=0.0308) for brook char and -0.47 (P=0.1171) for blacknose dace (Figure 5B-11 and 5A-12).

Discussion

Our primary objective was to examine the relative performance of populations among three streams and to infer the relationship between fish performance and water quality. To do this, we examined several population parameters related to condition and production of two fish species common to all three watersheds. The only significant differences identified for brook char among streams were in mean weight and condition factor. The mean weight of char was similar between the two watersheds with better water quality (e.g., higher ANC's), and fish in both those streams were heavier than char in the acid-sensitive stream. A different pattern was evident when considering the relationship between weight and length (e.g., condition factor). The condition factors of fish in the well-buffered stream and the acid-sensitive stream were similar. Fish in those streams had lower condition factors than in the intermediate stream. For Paine Run fish the combination of lowest condition factors and mean weights suggests that poor water quality may be affecting fish growth. Brook char condition factor among streams also was inversely related to density. However, this relationship was not strong considering that only 30% of the variability in condition factor could be accounted for by brook char density. Currently it does not appear that density-dependent interactions (e.g., competition for limited resources) are playing a major role in the performance of these char populations.

Although a pattern emerged showing increased production with increased acid-neutralizing capacity, annual production was not significantly different among streams and we found only weak evidence that the char populations in these three streams are currently limited or stressed by environmental influences. The ranges of annual production estimates were similar to brook char production estimates reported for four other headwater streams in Virginia and West Virginia (Lucchetti 1983) and were well within ranges reported by Waters (1992) for less fertile streams.

Annual production to biomass ratios were lower than reported elsewhere (Cooper and Scherer 1967, Lucchetti 1983, Neves and Pardue 1983, and Waters 1992). The low annual *P/* values may reflect a lower inherent productive capacity in these streams. Some of the variation between our estimates and other published estimates may be related to differences in methodology and sampling errors associated with population estimates, and capture efficiency of age 0+ fish (Neves and Pardue 1983).

Significant differences among the study streams were identified for condition factor, density, average weight, and mean biomass of blacknose dace. Piney River and Staunton River fish were heaviest and had the highest condition factors, but density and biomass were only intermediate or low among streams. Paine Run consistently had the most fish, highest standing stocks, lowest average weights, and lowest condition factors. Although not statistically significant, the inverse relationship between mean density and mean condition factor suggested that the well-being of blacknose dace was influenced by density. Improvements in the identification of age groups and increased sampling during biologically significant periods (e.g. spawning, seasonal changes) may help clarify density-dependent interactions.

There are inherent problems in attempting to assess environmental quality using indices like condition factor and mean weight of fish living in streams. As an illustration, we constructed a conceptual model depicting the relation between condition factor and mean weight of brook char and blacknose dace in the three study streams (Figure 5B-13). Initially, the relative positioning of the three streams along each axis appeared similar for both species. However, when also considering the relative densities of each species among streams (e.g., Piney River had the most brook char, while Paine Run had the most blacknose dace), answering the question "Which stream is best overall?" becomes problematic. On the basis of brook char densities, Piney River apparently is the best stream, Staunton River intermediate, and Paine Run the worst. The order is different for density of blacknose dace; Paine Run is best, Piney River intermediate, and Staunton River the worst. On the basis of condition factor and mean weight, both species appeared to be doing best in Staunton River and worst in Paine Run. The answer to the “Which stream is best” question depends on the answer to a reciprocal question: “Best for what?”

To clarify the relationships in our conceptual model, we suggest developing better age at length criteria, increased frequency of sampling, extension of sampling over multiple consecutive years, and inclusion of all fish species in all analyses.

Although water quality no doubt influences the performance of fish populations, we did not link known differences in ANC directly to population-level performance of brook char and blacknose dace. In addition to extension of the sampling program across several consecutive years to observe trends, future research should be directed at comparing available energy resources in streams with different ANC, and at linking resource availability with temporal variation in water quality. For example: examination of the availability and caloric content of food organisms could be linked to changes in growth, condition, and survival of fish in acidic waters.

References

Allen, K. R. 1949. Some aspects of the production and cropping of fresh waters. Transactions of the Royal Society of New Zealand 77:222-228.

Anderson, R. O., and S. J. Gutreuter. 1983. Length, weight, and associated structural indices. Pages 283-300 *In* L. A. Nielsen, and D. L. Johnson editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 62-73 *In* N. B. Armantrout editor. Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division, American Fisheries Society, Portland, Oregon.

Carlander, K. D. 1969. Handbook of freshwater fishery biology, volume 1. Iowa State University Press, Ames.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Transactions of the American Fisheries Society 94:40-52.

Chapman, D. W. . 1978. Production in fish populations. Pages 5-25 *In* S. D. Gerking editor. Ecology of freshwater fish production. Blackwell Scientific Publications, London, England.

Cooper, E. L., and R. C. Scherer. 1967. Annual production of brook trout (*Salvelinus fontinalis*) in fertile and infertile streams of Pennsylvania. Proceedings of the Pennsylvania Academy of Science Vol. 41. Philadelphia.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. Dept. of Agr., Forest Service, Southeastern Forest Experimental Station, Asheville, North Carolina.

Egglishaw H. J., and P. E. Shackley. 1977. Growth, survival and production of juvenile salmon and trout in a Scottish stream, 1966-1975. Journal of Fish Biology 11:647-672.

Haines, T. A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: A review. Transactions of the American Fisheries Society 110:669-707.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Science 45:834-844.

Hunt, R. L. 1974. Annual production by brook trout in Lawrence Creek during eleven successive years. Wisconsin Department of Natural Resources Technical Bulletin 82.

Lemly, A. D., and R. J. F. Smith. 1985. Effects of acute exposure to acidified water on the behavioral response of fathead minnows, *Pimephales promelas*, to chemical feeding stimuli. Aquatic Toxicology 6:25-36.

Lucchetti, G. L. 1983. Production of brook trout (*Salvelinus fontinalis*) in four headwater streams in the James River basin of Virginia and West Virginia. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Neves, R. J., and G. B. Pardue. 1983. Abundance and production of fishes in a small appalachian stream. Transactions of the American Fisheries Society 112:21-26.

Newman, R. M., and T. F. Waters. 1989. Differences in brown trout (*Salmo trutta*) production among contiguous sections of entire stream. Canadian Journal of Fisheries and Aquatic Science 46:203-213.

Power, G. 1980. The brook charr, *Salvelinus fontinalis*. Pages 141-203 *In* E. K. Balon, editor. Charrs: salmonid fishes of the genus *Salvelinus*. Dr. W. Junk, The Hague, Netherlands.

Ricker, W. E. 1946. Production and utilization of fish populations. Ecological Monographs 16:373-391.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: The Principles and Practice of Statistics in Biological Research Third Edition. W. H. Freeman and Company, New York, New York.

Waters, T. F. 1992. Annual production, production/biomass ratio, and the ecotrophic coefficient for management of trout in streams. North American Journal of Fisheries Management 12:34-39.

Waters, T. F. 1977. Secondary production in inland waters. Advances in Ecological Research 10:91-164.

Weatherley, A. H. 1972. Growth and Ecology of Fish Populations. Academic Press Inc., New York, New York.

Wootton, R. J. 1992. Ecology of Teleost Fishes. Chapman & Hall, London, England.

Zippen, C. 1958. The removal method of population estimation. Journal of Wildlife Management. 22:82-90.

Table 5B-1. RM ANOVA table of probabilities for differences in the median values of the estimated parameters among factors for brook char data using lower estimates of contributions to production by age 0+ fish from egg deposition to May 1994 sample.

Parameter	Factor	Chi^2	P
density (fish/100m^2)	stream	4.67	0.0970
	sample	3.32	0.5051
	age/habitat	25.5	<0.0001
mean weight (g)	stream	11.6	0.0030
	sample	5.10	0.1646
	age/habitat	24.0	<0.0001
standing stock (g/100m^2)	stream	0.89	0.6397
	interval	6.68	0.0354
	age/habitat	17.1	0.0007
production (g/100m^2)	stream	2.68	0.2617
	interval	1.06	0.5875
	age/habitat	4.33	0.2276

Table 5B-2. RM ANOVA table of probabilities for differences in the median values of the estimated parameters among factors for brook char data using upper estimates of contributions to production by age 0+ fish from egg deposition to May 1994 sample.

Parameter	Factor	Chi^2	P
density (fish/100m^2)	stream	4.67	0.097
	sample	3.32	0.5051
	age/habitat	25.5	<0.0001
mean weight (g)	stream	11.6	0.0030
	sample	5.10	0.1646
	age/habitat	24.0	<0.0001
standing stock (g/100m^2)	stream	0.894	0.6397
	interval	3.96	0.1382
	age/habitat	21.4	<0.0001
production (g/100m^2)	stream	4.13	0.1270
	interval	11.6	0.0030
	age/habitat	14.5	0.0023

Table 5B-3. Median values for estimated parameters identified as significant in RM ANOVAs performed on brook char data using lower estimates of contributions to production by age 0+ fish from egg deposition to May 1994 sample.

Parameter	Factor[a.]	Median
density (fish/100m^2)	age 0+ in pools	11
	age 1+ in pools	11
	age 0+ in riffles	2
	age 1+ in riffles	1
mean weight (g)	Paine Run	4.0
	Staunton River	15.6
	Piney River	5.5
	age 0+ in pools	3.4
	age 1+ in pools	49.8
	age 0+ in riffles	3.3
	age 1+ in riffles	28.1
standing stock (g/100m^2)	spring '93 - fall '93	36.8
	fall '93 - spring '94	28.6
	spring '94 - fall '94	179.1
	age 0+ in pools	140.0
	age 1+ in pools	388.4
	age 0+ in riffles	9.0
	age 1+ in riffles	12.0

a. Factor levels are specifically described.

Table 5B-4. Median values for estimated parameters identified as significant in RM ANOVAs performed on brook char data using upper estimates of contributions to production by age 0+ fish from egg deposition to May 1994 sample.

Parameter	Factor[a.]	Median
density (fish/100m^2)	age 0+ in pools	11
	age 1+ in pools	11
	age 0+ in riffles	2
	age 1+ in riffles	1
mean weight (g)	Paine Run[b.]	4.0
	Staunton River[b.]	15.6
	Piney River[b.]	5.5
	age 0+ in pools	3.4
	age 1+ in pools	49.8
	age 0+ in riffles	3.3
	age 1+ in riffles	28.1
standing stock (g/100m^2)	age 0+ in pools	140.0
	age 1+ in pools	388.4
	age 0+ in riffles	13.6
	age 1+ in riffles	12.0
production (g/100m^2)	spring '93 - fall '93	4.4
	fall '93 - spring '94	106.1
	spring '94 - fall '94	4.1
	age 0+ in pools	176.0
	age 1+ in pools	-41.0
	age 0+ in riffles	25.0
	age 1+ in riffles	0.0

a. Factor levels are specifically described.
b. Paine Run = low ANC; Staunton River = moderate ANC; Piney River = high ANC.

Table 5B-5. RM ANOVA and Mann-Whitney probability for differences in the median values of the estimated parameters among factors for blacknose dace.

Parameter	Factor[a.]	Chi^2 or T	P
density (fish/100m^2)	stream	14.3	0.0008
	sample	6.64	0.0842
	age/habitat	211.0	<0.0001
mean weight (g)	stream	7.00	0.0302
	sample	5.00	0.1718
	age/habitat	157.0	0.7075
standing stock (g/100m^2)	stream	9.33	0.0094
	interval	2.80	0.2466
	age/habitat	120.0	0.0027
production (g/100m^2)	stream	4.00	0.1353
	interval	5.20	0.0743
	age/habitat	78.0	0.5365

a. Stream and sample or interval factor results are from RM ANOVA and use Chi-square values; age/habitat factor results are from Mann-Whitney and use T values.

Table 5B-6. Median values for estimated parameters identified as significant in RM ANOVAs or Mann-Whitney tests performed on blacknose dace.

Parameter	Factor[a.]	Median
density (fish/100m^2)	Paine Run[b.]	18
	Staunton River[b.]	1
	Piney River[b.]	7
	dace in pools	19
	dace in riffles	1
mean weight (g)	Paine Run[b.]	2.0
	Staunton River[b.]	4.9
	Piney River[b.]	3.3
standing stock (g/100m^2)	Paine Run[b.]	40.0
	Staunton River[b.]	5.7
	Piney River[b.]	19.2
	dace in pools	43.4
	dace in riffles	1.2

a. Factor levels are specifically described.
b. Paine Run = low ANC; Staunton River = moderate ANC; Piney River = high ANC.

Table 5B-7. Summary of fish population data and total annual production estimates (g/m^2) for brook char in three streams with different acid neutralizing capacity (ANC) within Shenandoah National Park, Virginia.

Stream[a.]	Cohort[b.]	Mean population size (range)[c.]	Mean biomass (g/m^2)	Production *P*	*P*/B
Paine Run	0+ lower	480 (129-1,516)	2.2	1.7	0.8
	0+ upper	112,277 (129-410,687)	3.0	2.0	0.7
	1+	751 (10-2,527)	8.5	0.6	0.1
annual (lower)	total	1,231	10.7	2.3	0.2
annual (upper)	total	113,028	11.5	4.3	0.4
Staunton River	0+ lower	473 (165-1,123)	1.6	1.0	0.6
	0+ upper	5,062 (165-300,632)	2.4	2.2	0.9
	1+	750 (95-1,850)	4.3	1.8	0.4
annual (lower)	total	1,223	5.9	2.8	0.5
annual (upper)	total	5,812	6.7	4.0	0.6
Piney River	0+ lower	1,110 (379-2,181)	0.8	0.5	0.6
	0+ upper	122,808 (380-381,607)	1.9	3.4	1.8
	1+	914 (0-2,348)	20.1	4.3	0.2
annual (lower)	total	2,024	20.9	4.8	0.2
annual (upper)	total	123,722	22.0	7.7	0.4

a. Paine Run = low ANC, Staunton River = moderate ANC, Piney River = high ANC.
b. age 0+ values are presented as a range, age 1+ cohort = age 1+ and older.
c. age 0+ upper values include abundance estimates of potential eggs produced in the range.

Table 5B-8. Summary of fish population data and total annual production estimates (g/m^2) for blacknose dace in three streams with different acid neutralizing capacity (ANC) within Shenandoah National Park, Virginia.

Stream[a.]	Habitat	Mean population size (range)	Mean biomass (g/m^2)	Pproduction *P*	*P*/*B*
Paine Run	pools	2,999	1.5	0.03	0.02
		(2,017-4,577)			
	riffles	1,484	0.5	0.1	0.2
		(799-2,407)			
annual	total	4,483	2.0	0.1	0.1
Staunton River	pools	360	0.3	0.03	0.1
		(200-501)			
	riffles	49[b.]	N/A	N/A	N/A
		(0-147)			
annual	total	409	0.3	0.03	0.1
Piney River	pools	1,318	0.8	0.2	0.3
		(831-1,842)			
	riffles	368	0.04	0.01	0.3
		(119-821)			
annual	total	1,686	0.8	0.2	0.3

a. Paine Run = low ANC, Staunton River = moderate ANC, Piney River = high ANC.
b. No fish were captured in riffle habitat after the spring 1993 survey (146.67 fish), hence no biomass or production estimates were possible for blacknose dace in riffle habitat in Staunton River.

Table 5B-9. Median values of condition factor K (g/mm^3) by factor levels for brook char (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*) in three streams with different acid neutralizing capacity (ANC) within the Shenandoah National Park, Virginia.

Factor level	Brook char	Blacknose dace
Paine Run	0.93	0.88
Staunton River	0.99	1.01
Piney River	0.92	0.94
Spring 1993	0.93	0.94
Fall 1993	0.88	0.85
Spring 1994	1.08	1.14
Fall 1994	0.91	0.88
age 0+ pools	0.90	N/A
age 1+ pools	0.93	N/A
age 0+ riffles	1.00	N/A
age 1+ riffles	1.03	N/A
BND pools[a.]	N/A	0.90
BND riffles[a.]	N/A	0.92

a. BND = blacknose dace.

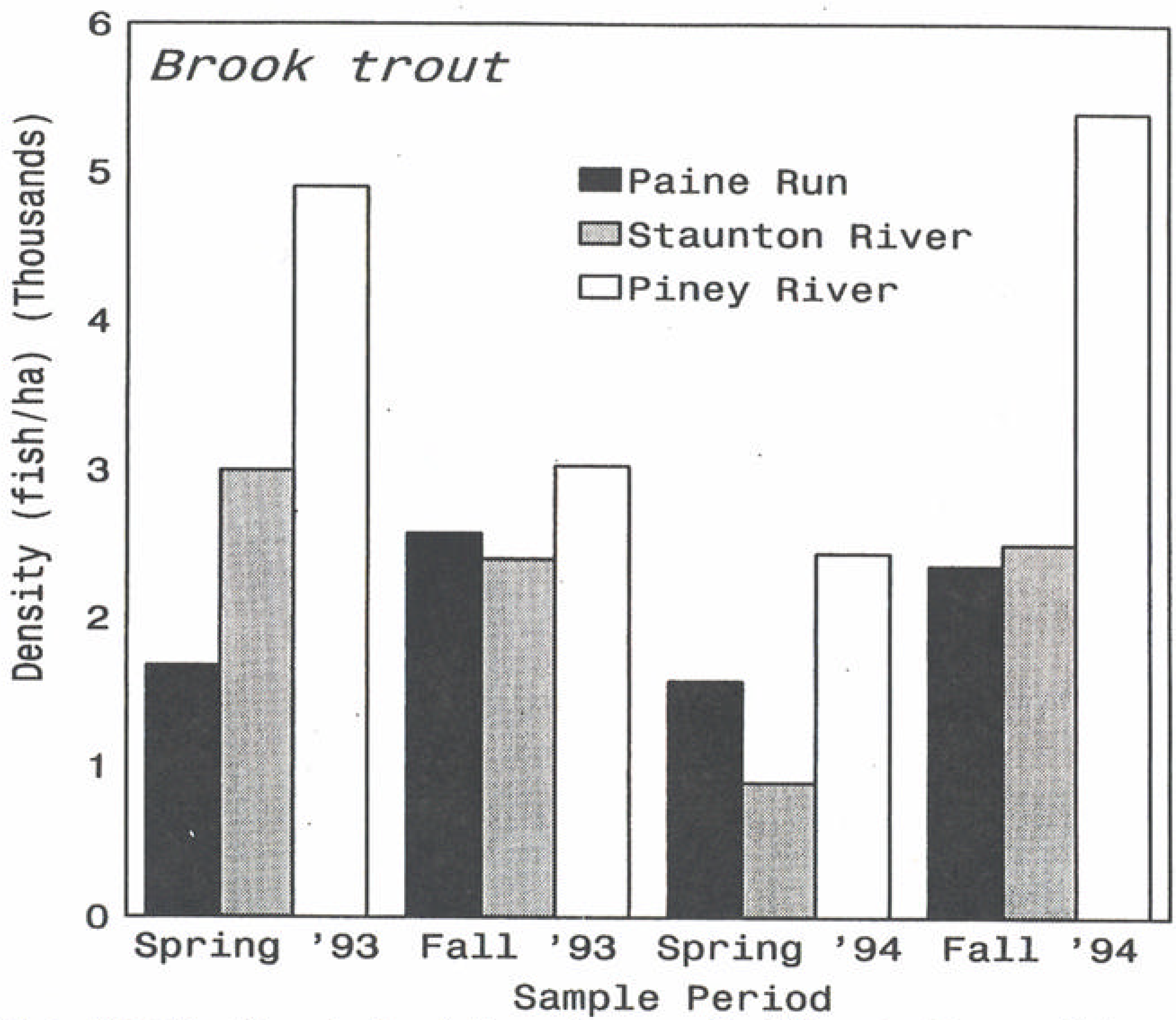

Figure 5B-1. Density of brook char in three streams with different acid-neutralizing capacity within the Shenandoah National Park, Virginia.

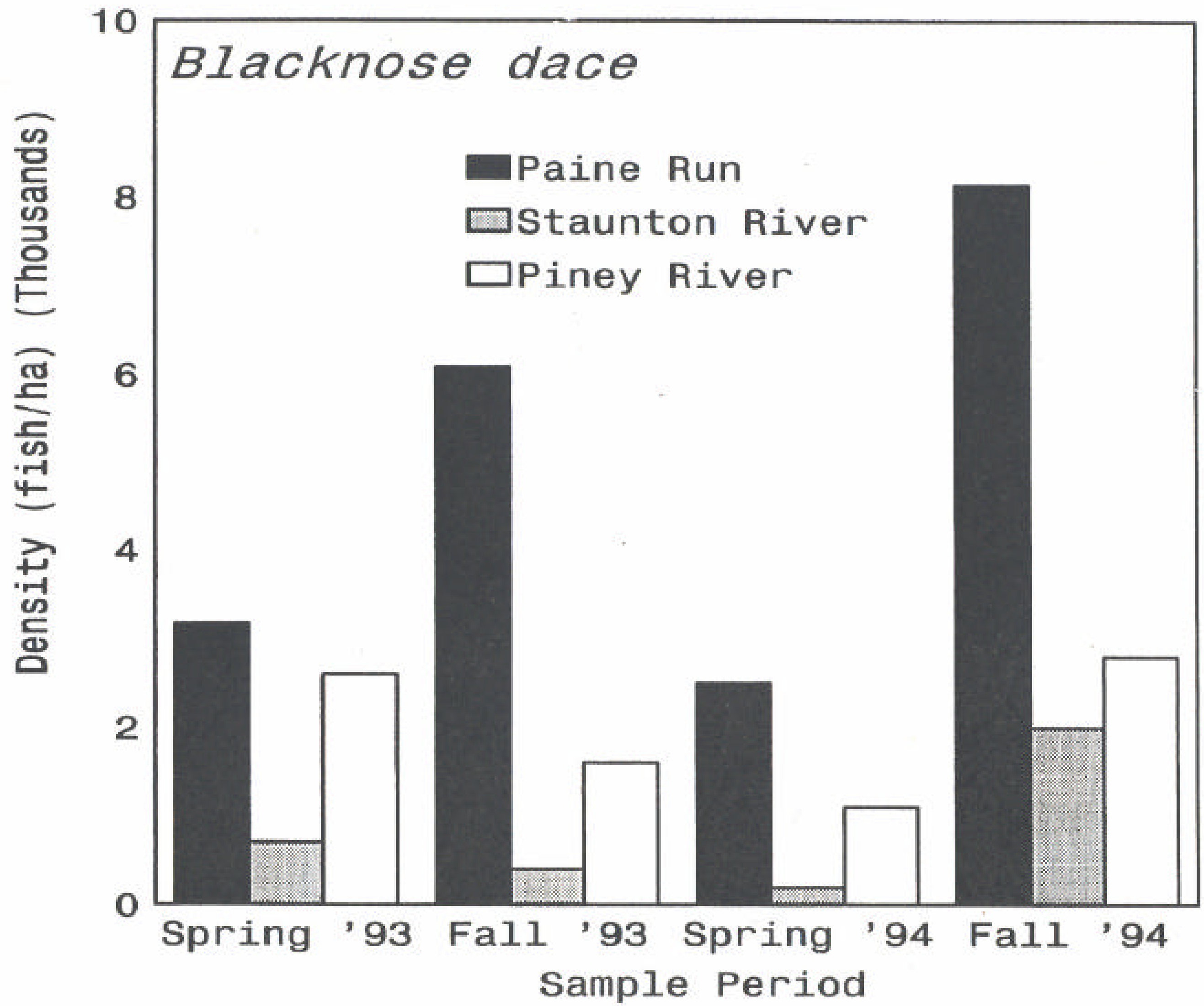

Figure 5B-2. Density of blacknose dace in three streams with different acid-neutralizing capacity within the Shenandoah National Park, Virginia

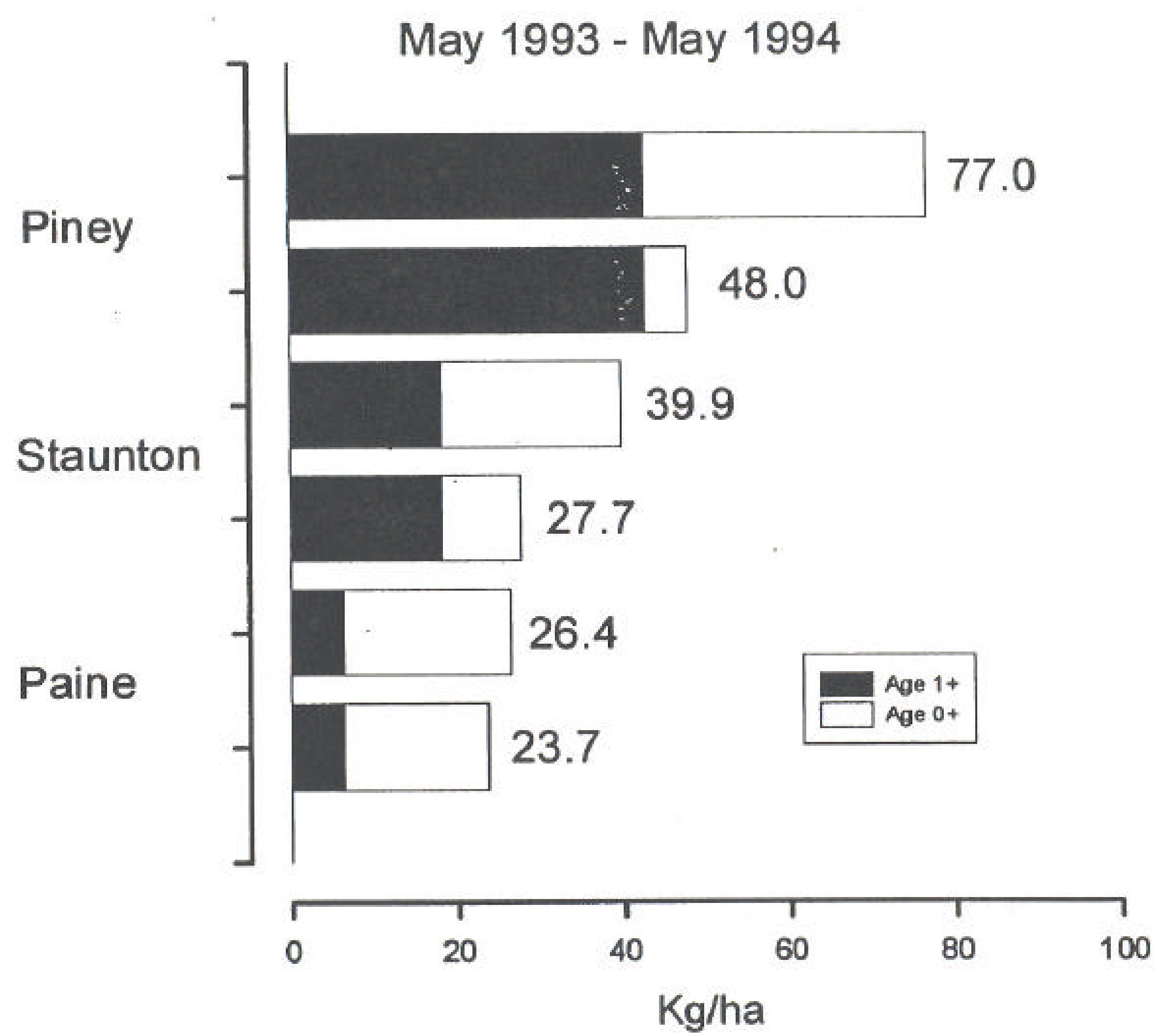

Figure 5B-3. Annual production of brook char in three streams with different acid-neutralizing capacity within the Shenandoah National Park, Virginia. Lower and Upper values for each stream reflect the estimated range of annual production by brook char.

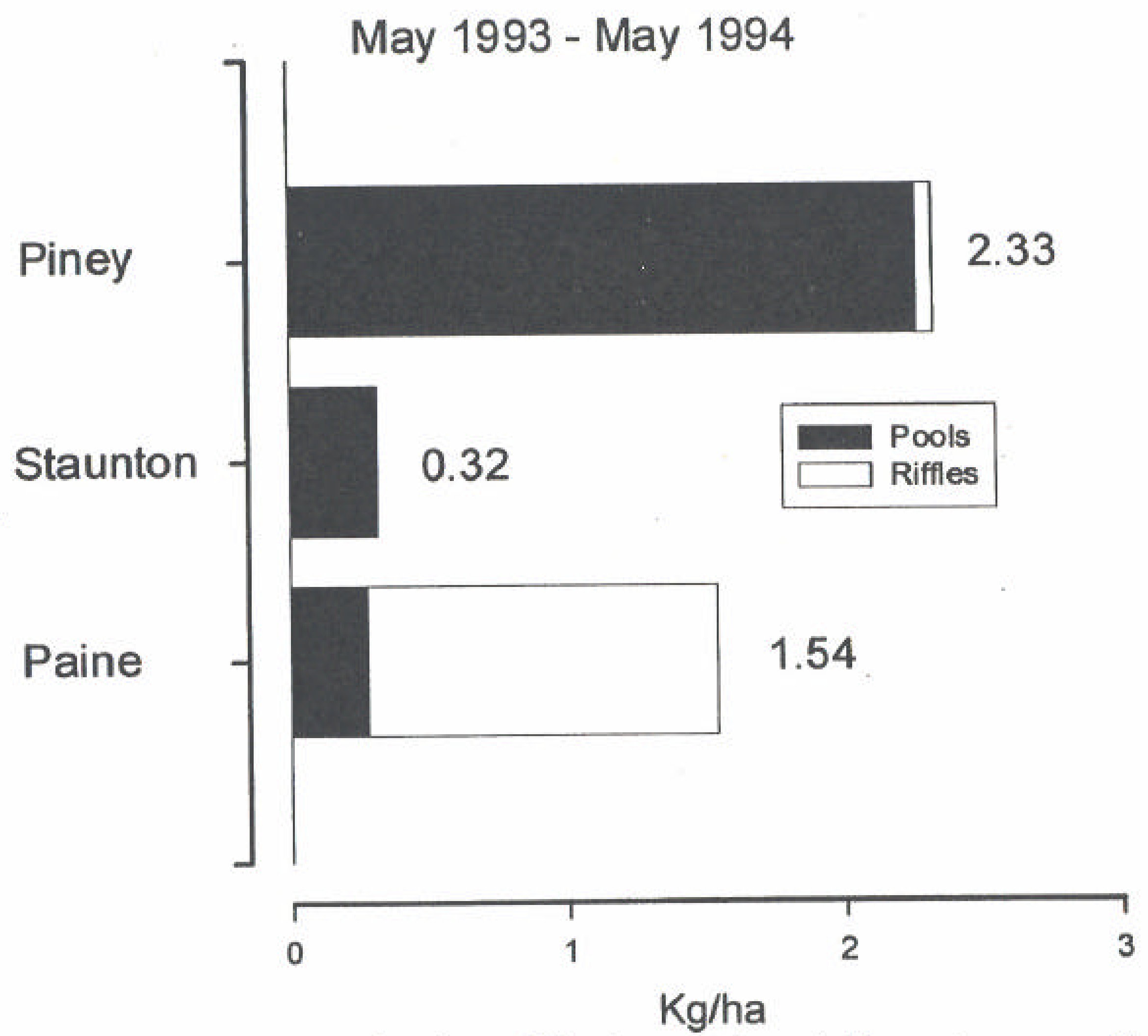

Figure 5B-4. Annual production of blacknose dace in three streams with different acid-neutralizing capacity within the Shenandoah National Park, Virginia

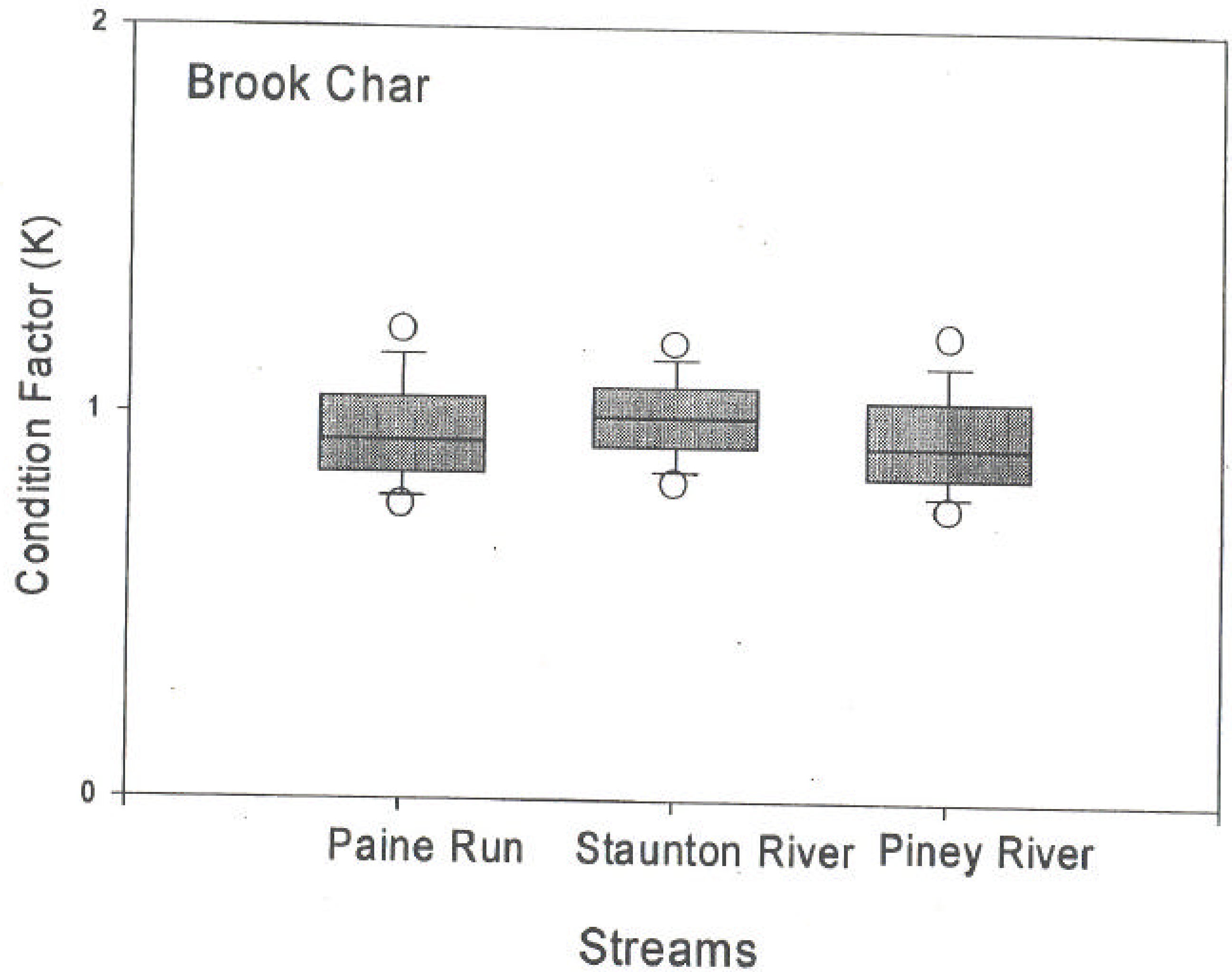

Figure 5B-5. Brook char condition factor (K) in gm/m^3 among three streams with different acid neutralizing capacity within the Shenandoah National Park, Virginia. Boxes encompass the 25th and 75th percentiles and the median; vertical capped lines show the 10th and 90th percentiles.

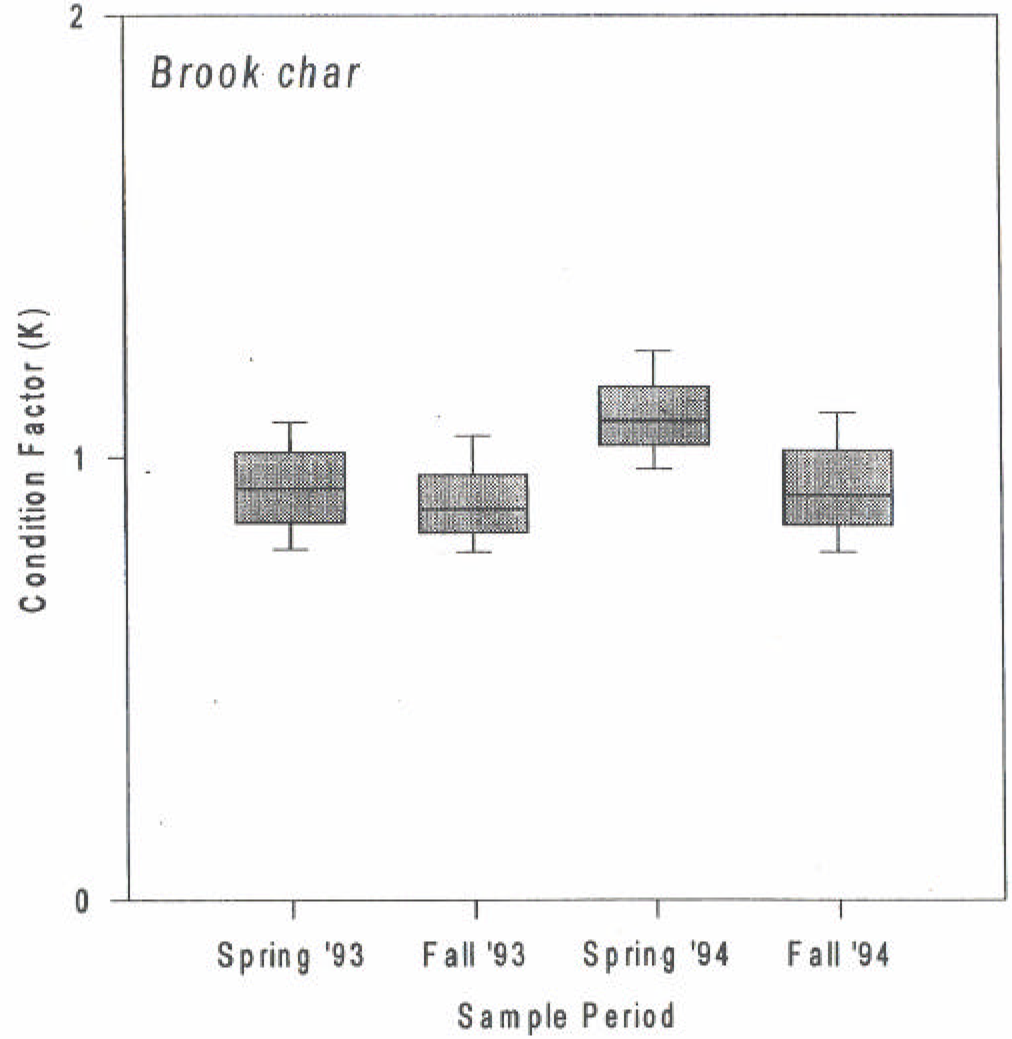

Figure 5B-6. Brook char condition factor (K) in gm/m³ among sampling periods conducted within the Shenandoah National Park, Virginia. Boxes encompass the 25th and 75th percentiles and the median; vertical capped lines show the 10th and 90th percentiles.

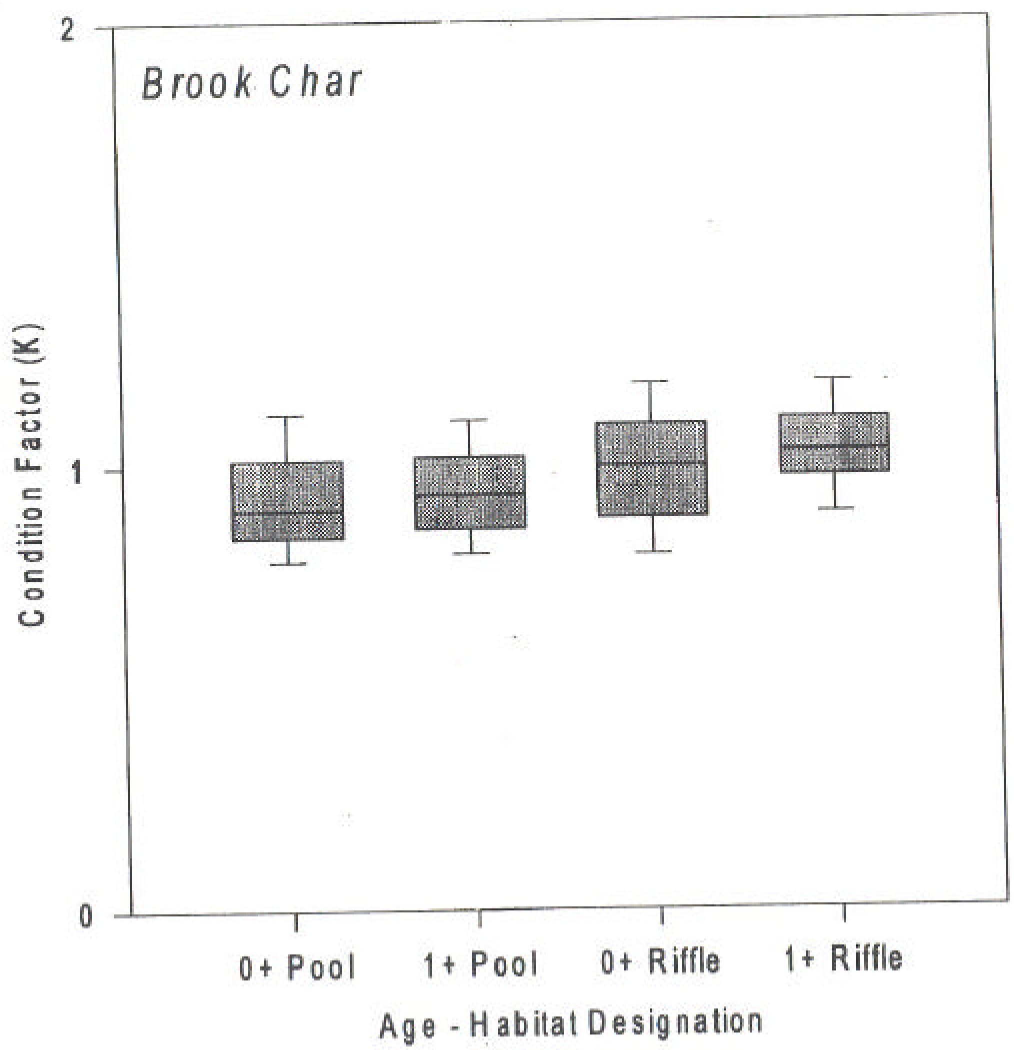

Figure 5B-7. Brook char condition factor (K) in gm/m^3 among age/habitat designations in the Shenandoah National Park, Virginia. Boxes encompass the 25th and 75th percentiles and the median; vertical capped lines show the 10th and 90th percentiles.

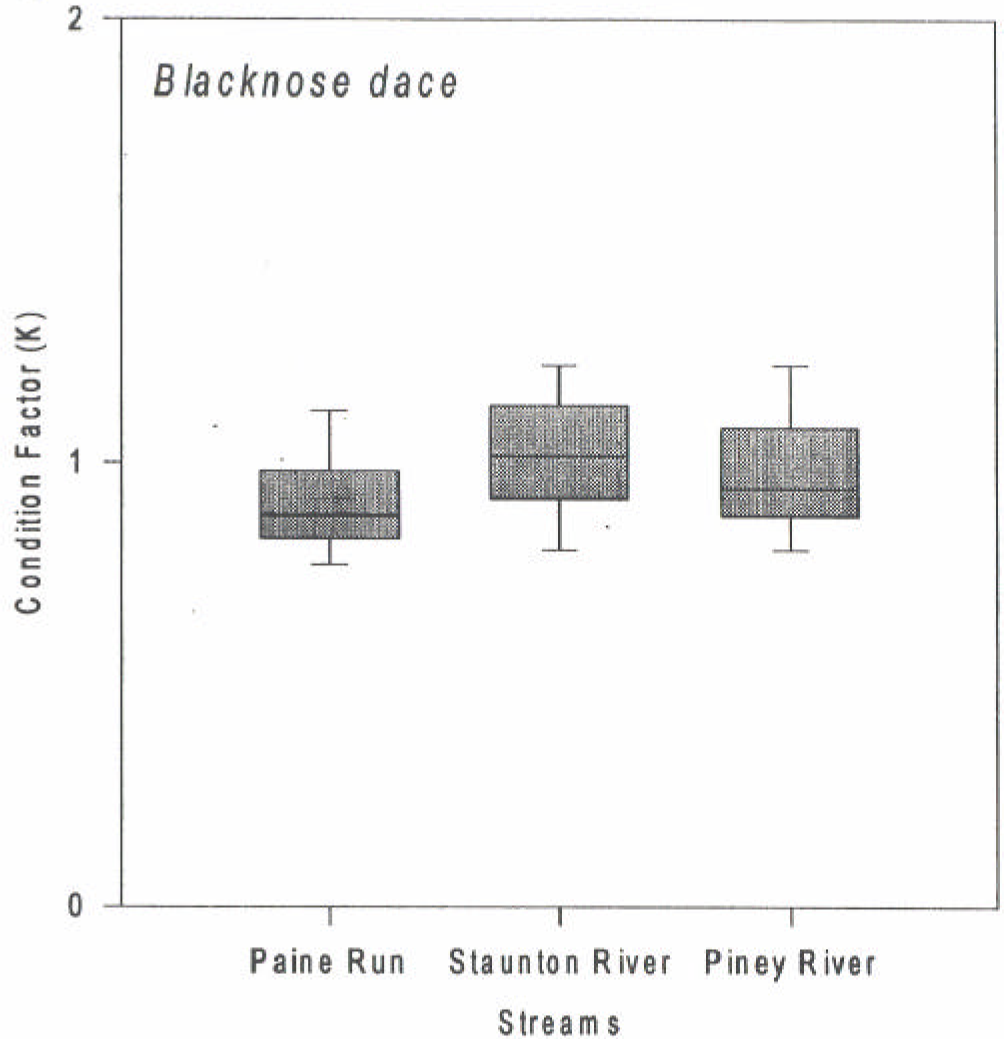

Figure 5B-8. Blacknose dace condition factor (*K*) in gm/m³ among three streams with different acid neutralizing capacity within the Shenandoah National Park, Virginia. Boxes encompass the 25th and 75th percentiles and the median; vertical capped lines show the 10th and 90th percentiles

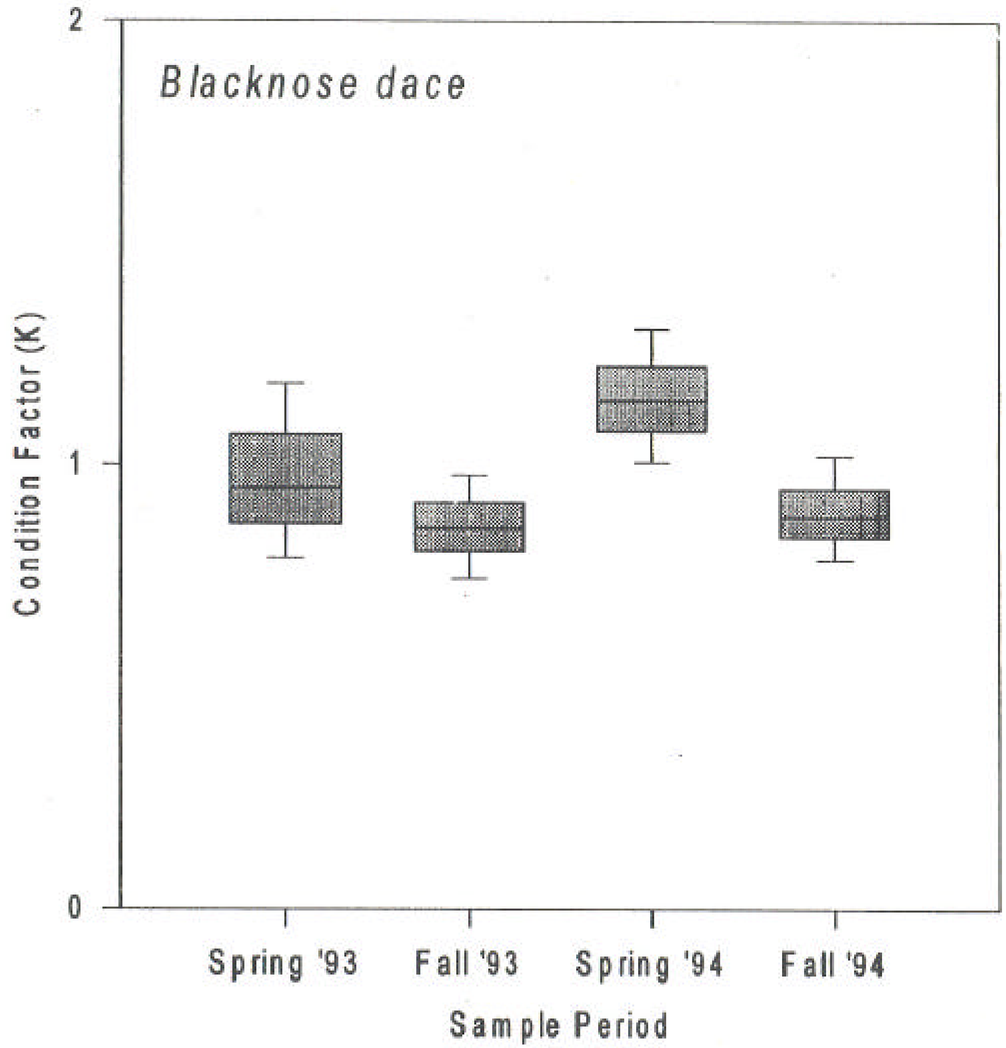

Figure 5B-9. Blacknose dace condition factor (*K*) in gm/m³ among sampling periods conducted within the Shenandoah National Park, Virginia. Boxes encompass the 25th and 75th percentiles and the median; vertical capped lines show the 10th and 90th percentiles

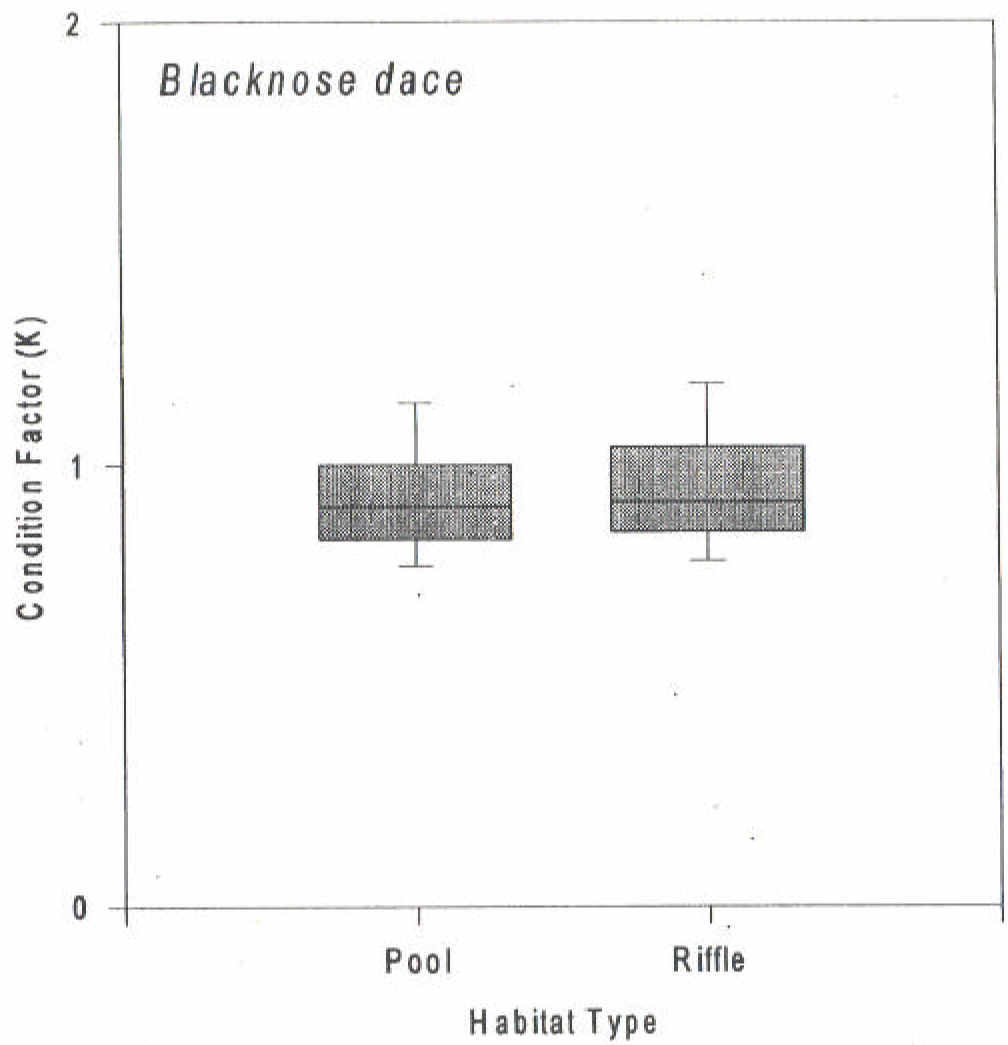

Figure 5B-10. Blacknose dace condition factor (K) in g/mm^3 between habitat types in the Shenandoah National Park, Virginia. Boxes encompass the 25th and 75th percentiles and the median; vertical capped lines show the 10th and 90th percentiles

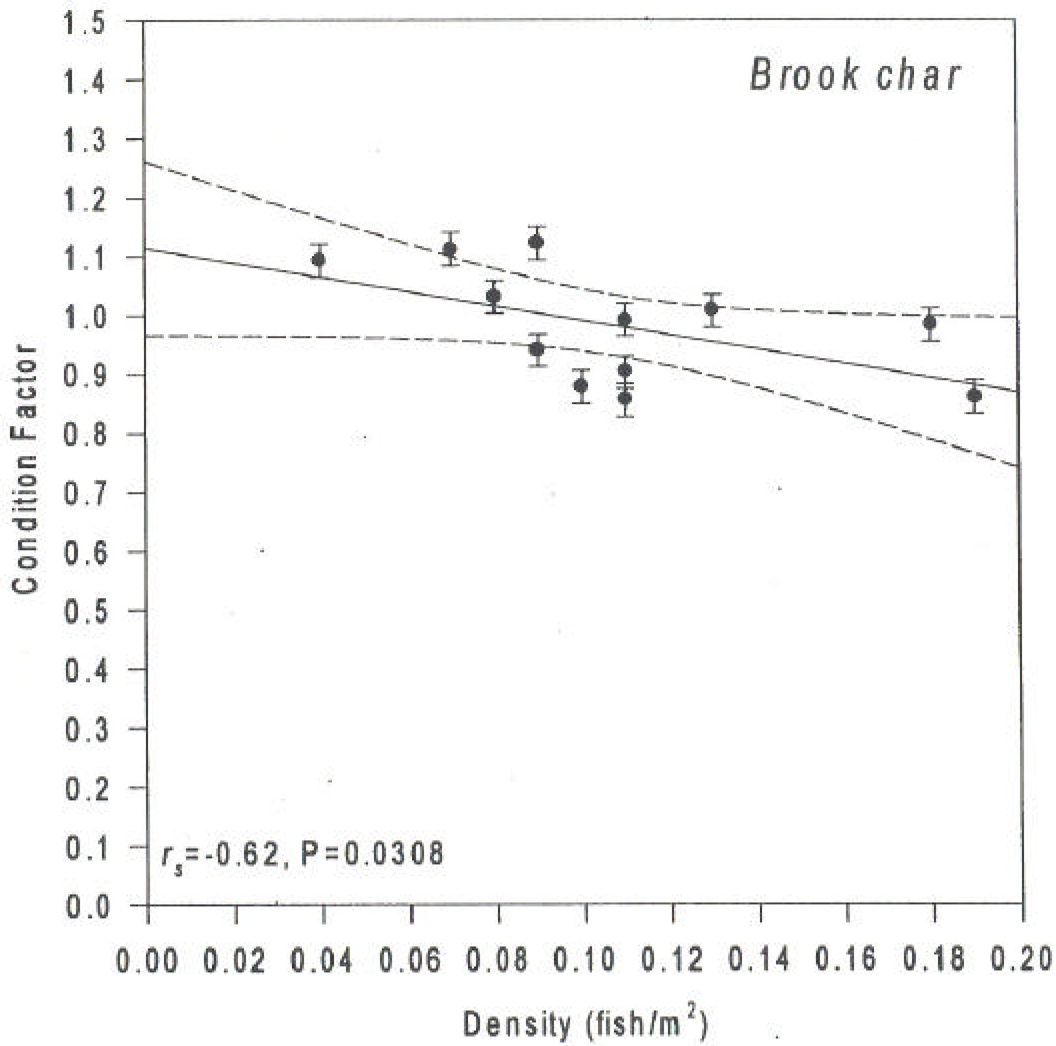

Figure 5B-11. Spearman's rank order correlation between brook char condition factor (*K*) and fish density among streams and sample periods. Error bars indicate 2 standard errors, solid line is the simple linear regression line through the data points, and dashed lines are the 95% confidence intervals about the regression line.

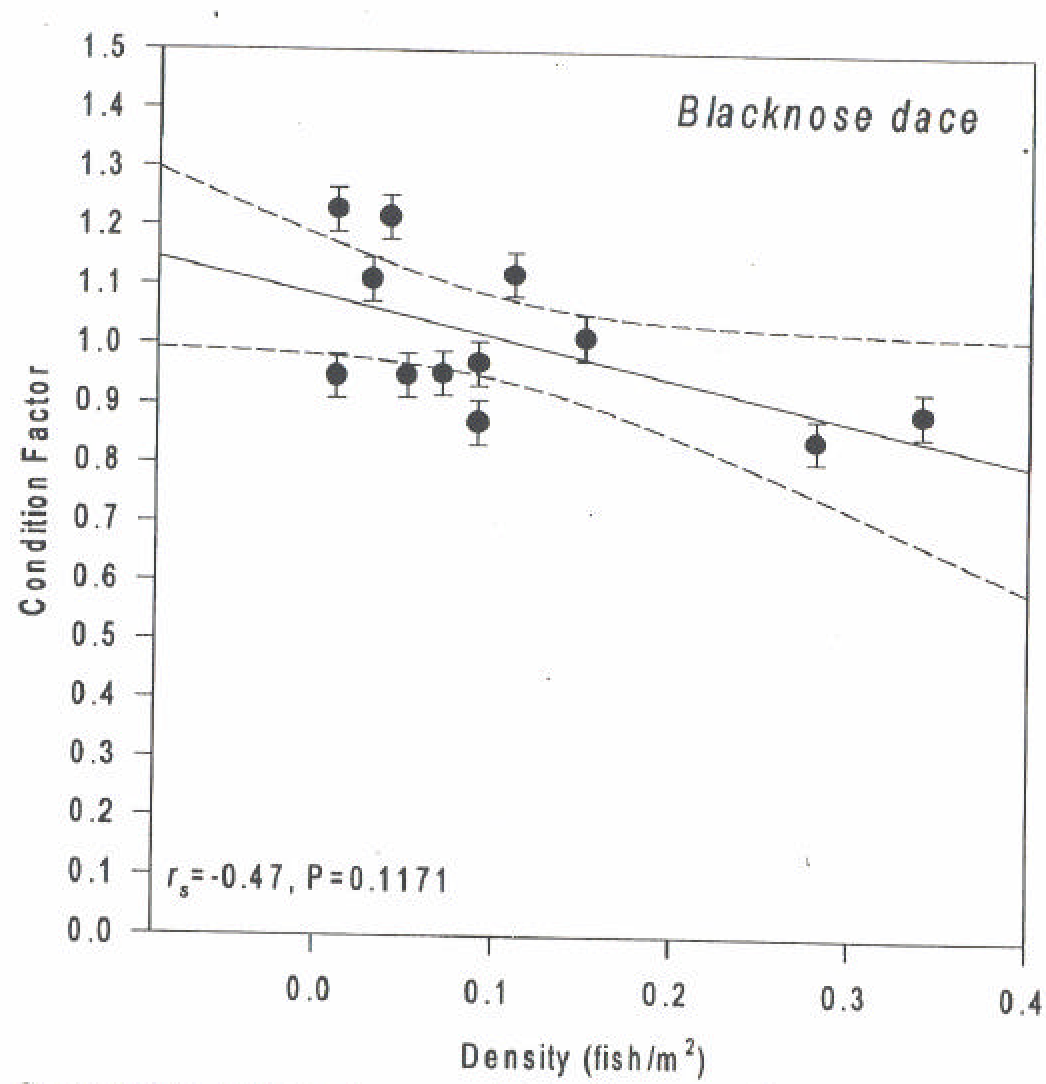

Figure 5B-12. Spearman's rank order correlation between blacknose dace condition factor (K) and fish density among streams and sample periods. Error bars indicate 2 standard errors, solid line is the simple linear regression line through the data points, and dashed lines are the 95% confidence intervals about the regression line.

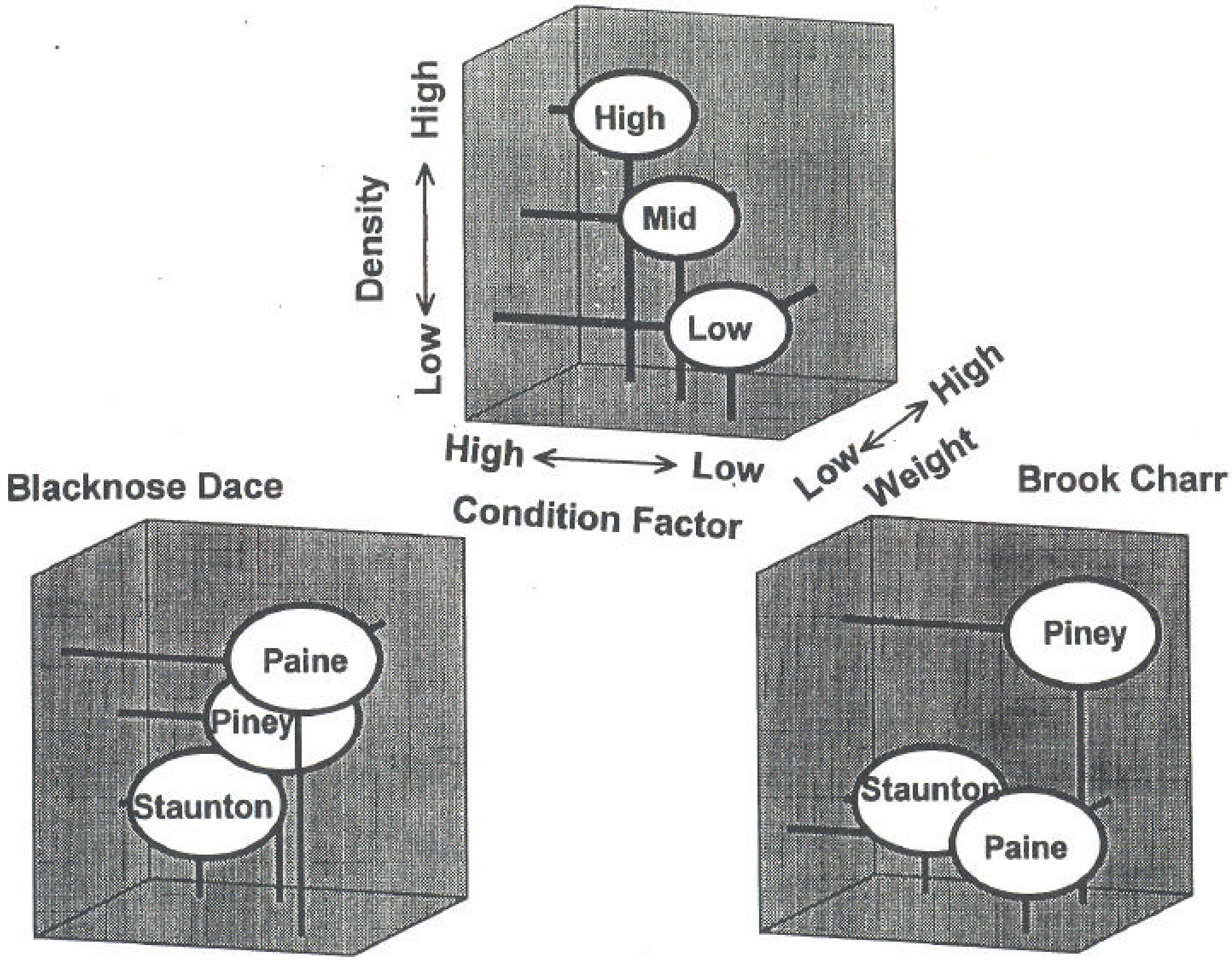

Figure 5B-13. Conceptual model relating condition factor, mean weight, and density of brook char and blacknose dace in three streams with different ANC in Shenandoah Naitonal Park, Virginia

Chapter 5C

Response of Brook Char (*Salvelinus fontinalis*), and Blacknose Dace (*Rhinichthys atratulus*) to Acidification in a Laboratory Stream

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Abstract

We evaluated movements of blacknose dace (Rhinichthys atratulus) and brook char (Salvelinus fontinalis) during exposure to artificial acidification in paired channels of a laboratory stream. The objectives of this study were to determine the ability of the fish to avoid depressions in ambient pH and to recognize and use a neutral-pH microhabitat refuge. We tested fish avoidance behavior by manipulating food and the delivery of a pulse of acidified water. Both blacknose dace and brook char avoided the acid pulse (ambient pH reduced from 7.2 to 5.1) by sheltering in the pH-neutral refuge. Extensive field sampling in refuge microhabitats before and during episodic acidification is needed to determine changes in the distributional patterns of these species associated with acid precipitation events.

Introduction

Atmospheric deposition of acidifying pollutants has been linked to acute, short-term reductions in pH during high stream discharge (Gagen 1991). These acidic events have been well documented in poorly buffered headwater streams of Virginia (Webb et al. 1994). Increases in pH and acid neutralizing capacity (ANC) from upstream to downstream have been related to inputs of relatively alkaline water from spring seeps and tributaries (Sharpe and DeWalle 1990). This spatial variability creates the potential for relatively alkaline microhabitats to act as refugia for fishes exposed to periodic acidic episodes.

Knowledge of the relationship between the acidification of surface water and aquatic ecosystems has increased dramatically over the last twenty years (Woodward et al. 1989; Charles 1991). Haines (1981) related acidic precipitation to reductions in fish abundance, increased mortality, and especially reproductive failure which could lead to the loss of valuable recreational fisheries. More recently, Gagen (1991) attributed reduced brook char (*Salvelinus fontinalis*) densities to increased mortality rates and downstream movement to acidic episodes. Other researchers have reported behavioral responses of stream salmonids to acid events including downstream migrations and congregation at alkaline water inputs (Leivestad and Muniz 1976; Hall et al. 1980; Muniz and Leivestad 1981; Watt et al. 1983; Gagen et al. 1989). In laboratory studies, fish have demonstrated behavioral avoidance of a variety of environmental variables including low pH and high Al concentrations (Whitmore et al. 1960; Hill et al. 1981; Jones et al. 1985; Gunn and Noakes 1986). Unfortunately, most laboratory studies have not accounted for other environmental variables, such as food availability or sensory and physiological preconditioning (acclimation) to extreme conditions (Gunn 1986), which may also elicit an avoidance response. And although brook char have been shown to acclimate to low pH (Guthrie 1981), response to acidification by nongame fishes is not well known (see review in Charles 1991).

We tested the effect of water acidification on movement of brook char and blacknose dace (*Rhinichthys atratulus*) in the paired channels of a laboratory stream. The objectives of this study were to determine the ability of the fish: (1) to avoid depressions in the ambient pH of their environment; and (2) to recognize and use a pH neutral microhabitat refuge during acute reductions in pH. Brook char and blacknose dace indigenous to an acid-sensitive stream (Paine Run) of Shenandoah National Park (SNP), Virginia were selected for these experiments because they commonly occur together in streams vulnerable to acidic episodes. Furthermore, Paine Run fish are exposed to spatially variable water chemistry from tributaries with water more alkaline than the main stem, creating natural conditions that could account for acclimation.

Methods

Ninety brook char, 52-81 mm TL (young-of-year fish), and one hundred thirty blacknose dace, 52-78 mm TL (adult fish), were collected from Paine Run by electrofishing. Brook char were maintained in a "Living Stream" (Frigid Units, Inc., Toledo, OH) equipped with a one-third horsepower chiller unit. Blacknose dace were maintained in three individual 37.9 L aerated aquaria. All fish received a daily ration of a commercially prepared diet. A fungal disease in one of the aquaria housing blacknose dace reduced that collection by 10 percent. No other mortality attributable to handling stress or exposure to acidic waters for either species was observed during the remainder of the experiments. Experiments were conducted from August 31 through December 31, 1994.

Tests were conducted within paired channels of a laboratory stream of overall dimensions: 106.7 cm wide by 518.2 cm long by 15.2 cm deep (Figure 5C-1). The stream was partitioned into six zones of equal surface area (0.43 m^2) by marks placed along the interior of the channel walls. A center wall (15.2 cm high) divided the paired channels from the upper end of the laboratory stream to the upper end of the two lower most zones. The entire laboratory stream was mounted on PVC stands within a hatchery style concrete raceway (9500 L capacity) at the Aquaculture Facility of Virginia Tech. An adjacent raceway was used as a reservoir for water during each experimental trial. A single layer of washed stream gravel (6.3-24.9 mm diameters) was added to the bottom of the laboratory stream for substrate. The raceway housing the laboratory stream was enclosed in a black plastic shroud. A diffused lighting system was mounted inside the frame supporting the shroud. During an experimental trial, observers stood on a platform mounted on the reservoir raceway to view and count fish through a small opening in the top of the shroud.

Water was pumped from the reservoir to two head tanks (757.1 L capacity) mounted about 365 cm above the raceway housing the laboratory stream. Water was gravity-fed from the head tanks into small mixing zones at the head of each channel (0.16 m^2), from where it was forced under a baffle to produce uniform or "plug" flow. Plug flow was defined as a common volume of water flowing in one direction down the length of a paired channel without mixing with water in the other paired channel. Plug flow was determined by running 10 preliminary trials using a dye to trace flow down the length of each channel. Current velocity was measured at 30.5 cm intervals along the length of the two channels with a Marsh-McBirney model 201D water current meter. Water current velocity in each channel was similar: 0.3 m/s (+/- 0.05 m/s). Water exited the laboratory stream over a spill dam at the downstream end. A plastic grate (0.64 cm mesh) along the top edge of the spill dam prevented fish from exiting the system with used water.

Well water was used during brook char experimental trials, when temperatures were 10 degC +/- 1 degC, and pH was 8.2 +/- 0.1. Blacksburg municipal water was used for blacknose dace experimental trials Ambient pH of this water during experimental trials was 7.2 (+/- 0.1 unit). The reservoir raceway was filled and allowed to sit overnight with agitators running to eliminate chlorine. Sulfuric acid (H_2SO_4) was added to the reservoir before each experimental trial to reduce the ambient pH of the experimental water to 7.2 (+/- 0.1 unit).

Agitators were used to assure complete mixing and pH readings were made at 1 m intervals and at the bottom, mid-depth, and surface along the length of the reservoir before initiating an experimental trial. All pH measurements were made using a YSI Model 58 pH meter (Yellow Springs, OH). Fifteen randomly selected fish were selected for each trial and were returned to a separate holding tank after that trial was completed. Brook char were used ten times during all experimental trials conducted, and blacknose dace were used nine times. Fish were introduced into the downstream end of the laboratory stream and allowed 5 min to adjust before starting gravity flow and initiating food or acid delivery. Fish in each of the six zones were counted every 30 sec during every 30 min trial. All fish from a collection were used prior to reusing fish in subsequent trials. During fifteen preliminary trials (900 observations) with each species no food or acid was added to ensure that fish were not using either channel preferentially. Thirty trials (1800 observations) were then run with each species, fifteen with food additions to one of the paired channels, and an additional fifteen with food and acid additions together. Trials with food alone were used to test if food affected fish distribution. Trials with food and acid combined were used to test if the fish actively avoided acid pulses.

As suspension consisting of 6 g of commercially available frozen brine shrimp in 500 ml water was delivered to brook char by peristaltic pump at a rate of about one drip every 3 to 4 sec. Blacknose dace received commercial flake food delivered by a Sweeney Model AFT 1-QA automated shaker feeder at a rate of 0.2 sec of shake time every 30 sec.

Experimental channels were acidified by introducing a 20% solution of H_2SO_4 into the mixing zone above the baffle via peristaltic pump. Complete mixing of the acid solution and experimental stream water was ensured by the extreme agitation of the gravity fed water as it emerged from the head tank deliver pipe. Ambient pH of water in an acidified channel was reduced from 7.2 to 5.13 (+/- 0.1 unit) during an experimental trial (Figure 5C-2). No statistical difference existed between either channel in the magnitude of the pH reduction.

The design of the laboratory stream allowed independent control of water, pH, and food availability in either channel during a trial. Initial selection of a channel for food or acid additions was determined by the flip of a coin, channel selection was then alternated during subsequent trials until a total of fifteen trials had been completed in each of the paired channels.

Statistical Analyzes

We used a G-goodness of fit test for significant differences in fish distribution. Expected frequencies were based on hypotheses extrinsic to the sampled data (Sokal and Rohlf 1995); for preliminary trials without food or acid additions, we hypothesized that the fifteen fish in a trial would use all six zones of the laboratory stream uniformly (e.g., on average 2.5 fish observed per zone over the course of a trial). In trials where food alone was introduced, we similarly hypothesized that fish would use each zone of the laboratory stream equally. In trials where food and acid were introduced together, we based the expected frequencies on the frequencies observed during food only trials. For each test there were 5 degrees of freedom. All figures present fish distributions in a linear arrangement where zone 1 is always nearest the input of a given stimulus, and zone 6 is always furthest from the stimulus (Figure 5C-3).

Results

The initial experiments, which included 900 observations per species, were used to evaluate if fishes would use either of the paired channels preferentially without any stimulus other than water (pH = 7.2) flowing through the laboratory stream. The distribution of both species within the laboratory stream was uniform; brook char ($G = 5.4$, $P>0.50$) nor did blacknose dace ($G = 5.9$, $P>0.40$) showed preference for any of the six zones between the two channels.

Brook Char Responses - Food

In contrast to the initial trials, the distribution of brook char offered a suspension of brine shrimp was not random (Figure 5C-4); the fish showed a marked preference for the channel that received inputs of food ($G = 11.8$, $P<0.05$). Furthermore, char increased their use of zone 1 (e.g., the zone nearest to food inputs) more than any other zone within the channel receiving food. On average, 41.5% of the fish were observed in this area of the laboratory stream during these trials. We used the observed frequencies of zone use as indicated in Figure 5C-4 as the expected values (e.g., the control) in subsequent experiments that combined food and acid.

Brook Char Responses - Food and Acid

Brook char clearly avoided the acidified channel (Figure 5C-5; $G = 77.5$, $P<0.001$) and increased of the non-acidified channel. Use of the zone furthest from acid and food inputs increased by 47.5% over the expected frequency (Table 5C- 1).

Blacknose Dace Responses - Food

The distribution of blacknose dace shifted from uniform to a distinct preference for the channel that received food inputs ($G = 17.9$, $P<0.005$); Figure 5C-6). On average, 46.3% of blacknose dace were observed in the zone second nearest to food inputs. We used the observed frequencies of zone use as indicated in Figure 5C-6 as the expected values in subsequent experiments that combined food and acid.

Blacknose Dace Responses - Food and Acid

Blacknose dace clearly avoided the acidified channel (Figure 5C-7; $G = 41.4$, $P<0.001$) and increased use of the channel receiving only gravity fed water. Use of the zone immediately clear of acid and food inputs increased by 52.1% over the expected frequency (Table 5C-1).

Discussion

Both brook char and blacknose dace actively avoided reductions of ambient pH from 7.2 to 5.13 and sheltered in a pH neutral microhabitat refuge (e.g., the channel receiving only gravity fed water). Availability of other resources (e.g., food) did not deter fish from leaving an experimental channel after it was acidified. The lowest level of pH in these experiments was higher than that recorded during a 1993 acidic event in Paine Run (e.g., pH reduced from 5.8 to 4.86 during that episode). The lower limit for brook char survival is pH 4.5 (Power 1980), and waters below pH 5.5 are considered borderline (Schofield 1976). Waters ranging in pH from 5.0 to 5.9 have been reported to cause mortality in different life stages of blacknose dace (Johnson et al. 1987, Schofield and Driscoll 1987, Kretser et al. 1989, and Halliwell 1989). These results suggest that sensory or physiological acclimation is not a factor reducing the likelihood that Paine Run fish will avoid acidic pulses.

However, inferences made from behavior observed in a controlled environment may not be applicable to behavior in a fish's natural habitat. Although Neville (1985) used laboratory data to hypothesize that juvenile salmonids in the wild could escape death by sheltering in pH neutral refugia, field observations have demonstrated that wild fish do not always exhibit sheltering behavior (Gagen 1991).

The alkalinity of Lefthand Hollow, the lower most tributary of Paine Run (see Chapter 1), is more than double that the main stem throughout the spring and summer seasons (R. Webb personal communication). Lefthand Hollow therefore offers resident fish populations a potential refuge from acidic episodes. Average abundance of brook char, however, was lower than in two other park streams with higher ANC (see Chapters 1 and 2). But blacknose dace abundance in Paine Run, although not high in main stem of Paine Run near Lefthand Hollow compared to other reaches within Paine Run, was significantly higher than in those other streams. This seems contradictory considering the mobility of the two species observed in these experiments. Brook char were the more mobile of the two species as evidenced by the strength of their avoidance reaction. Brook char moved as far as possible from the acid input whereas blacknose dace typically moved only until they were out of the acid pulse.

It would seem that given equal proximity to a refuge, the more mobile species would benefit most during the onset of acidic conditions. This does not appear to be the case in Paine Run. Gagen (1991) attributed diminished brook char densities during acid events in acid-sensitive streams of the Northern Appalachian Plateau not only to direct mortality but also and especially to downstream movement. These emigrations occurred in spite of the availability of microhabitat refugia. Gagen further suggested that downstream movement by brook char was a passive response to severe physiological stress caused by the combination of low pH and high Al concentrations. We did not evaluate the potential for an adverse synergistic relationship between pH and Al concentrations to influence active avoidance. It is possible that the relatively low densities of brook char in Paine Run result from this type of passive downstream displacement.

Gagen (1991) also hypothesized that alkaline tributaries could provide nursery areas from which populations could recolonize the main stem of a stream after extreme conditions had passed. In a separate but related study (Chapter 1), we found blacknose dace in Lefthand Hollow but not in any other tributary of the three study streams. Despite poor water quality (lower ANC, pH, and calcium), blacknose dace populations were highest in Paine Run, where Lefthand Hollow may be providing refuge or nursery habitat from which main stem Paine Run populations are supplemented. Movement of blacknose dace into the main stem of Paine Run from Lefthand Hollow could account for the persistence of blacknose dace and perhaps even the observed differences in abundance between Paine Run and the other two SNP streams.

Future research aimed at clarifying some of the inconsistencies between field and laboratory data in this study should include extensive field sampling for fish movements in and out of pH neutral refugia before, during, and after episodic acidification, the identification of all alkaline microhabitats accessible to fish populations, and incorporating additional factors into avoidance experiments conducted in the laboratory stream. Clearly, both species exhibited an adaptive response to sublethal pH depressions. These experiments are an important preliminary step in understanding the relationship between behavioral modifications, acidic episodes, and the resilience of fish population in acid-sensitive streams.

References

Charles, D. F., editor. 1991. Acidic Deposition and Aquatic Ecosystems. Springer-Verlag, New York, New York.

Gagen, C. J. 1991. Direct effects of acidic runoff episodes on the distribution and abundance of fishes in streams of the Northern Appalachian Plateau. Ph.D. diss., The Pennsylvania State University, University Park, Pennsylvania.

Gagen, C. J., W. E. Sharpe, and W. G. Kimmel. 1989. Pumping alkaline groundwater to restore a put-and-take trout fishery in a stream acidified by atmospheric deposition. North American Journal of Fisheries Management 9:92-100.

Gunn, J. M. 1986. Behavior and ecology of salmonid fishes exposed to episodic pH depressions. Environmental Biology of Fishes 12:241-252.

Gunn, J. M., and D. L. G. Noakes. 1986. Avoidance of low pH and elevated Al concentrations by brook charr (*Salvelinus fontinalis*) alevins in laboratory tests. Water, Air and Soil Pollution 30:497-503.

Guthrie, C. A. 1981. Acclimation of brook trout (*Salvelinus fontinalis*) to acidified waters. M.S. Thesis. Cornell University, Ithaca, New York.

Haines, T. A. 1981. Acidic precipitation and its consequences for aquatic ecosystems: A review. Transactions of the American Fisheries Society 110:669-707.

Hall, R. J., G. E. Likens, S. B. Fiance, and G. R. Hendrey. 1980. Experimental acidification of a stream in Hubbard Brook Experimental Forest, New Hampshire. Ecology 61:976-989.

Halliwell, D. B. 1989. A classification of streams in Massachusetts. Ph.D. Dissertation. Department of Forestry and Wildlife Management, University of Massachusetts, Amherst, MA.

Hill, L. G., G. D. Schnell, and W. J. Matthews. 1981. Locomotor responses of the stripped bass, *Morone saxatilis*, to environmental variables. The American Midland Naturalist 105:139-148.

Johnson, D. W., H. A. Simonin, J. R. Colquhoun, and F. F. Flack. 1987. In situ toxicity tests of fishes in acidic waters. Biogeochemistry 3:181-208.

Jones, K. A., T. S. Hara, and E. Scherer. 1985. Behavioral modifications in arctic char (*Salvelinus alpinus*) chronically exposed to sublethal pH Physiological Zoology 58:400-412.

Kretser, W. A., J. Gallagher, and J. Nicolette. 1989. Adirondack lakes study 1984-1987: An evaluation of fish communities and water chemistry. Adirondack Lakes Survey Corporation, Ray Brook, NY.

Leivestad, H., and I. P. Muniz. 1976. Fish kill at low pH in a Norwegian river. Nature 259:391-392.

Muniz, I. P., and H. Leivestad. 1981. Toxic effects of aluminum on the brown trout, *Salmo trutta* L. Pages 320-321 *In* D. Drablos, and A. Tollan editors. Proceedings of the International Conference on the Ecological Impact of Acid Precipitation. SNSF Project, As-NLH, Norway.

Neville, C. M. 1985. Physiological response of juvenile rainbow trout, *Salmo gairdneri*, to acid and aluminum-prediction of field responses from laboratory data. Canadian Journal of Fisheries and Aquatic Science 42:2004-2019.

Power, G. 1980. The brook charr, *Salvelinus fontinalis*. Pages 141-203 *In* E. K. Balon, editor. Charrs: salmonid fishes of the genus *Salvelinus*. Dr. W. Junk, The Hague, Netherlands.

Schofield, C. L. 1976. Acid precipitation: effects of fish. Ambio 5:228-230.

Schofield, C. L., and C. T. Driscoll. 1987. Fish species distribution in relation to water quality gradients in the North Branch of the Moose River basin. Biogeochemistry 3:63-85.

Sharpe, W. E., and D. R. DeWalle. 1990. Acid precipitation and water quality in Pennsylvania: Making the connection. Pages 452-465 *In* S. K. Majumdar, and R. R. Parizek editors. Water Resources in Pennsylvania: Availability, Quality, and Management. Pennsylvania Academy of Science, Philadelphia.

Sokal, R. R., and F. J. Rohlf. 1995. Biometry: The Principles and Practice of Statistics in Biological Research Third Edition. W. H. Freeman and Company, New York, New York.

Watt, W. D., C. D. Scott, and W. J. White. 1983. Evidence of acidification of some Nova Scotian rivers and its impact on Atlantic salmon, *Salmo salar*. Canadian Journal of Fisheries and Aquatic Science 40:462-473.

Webb, J. R., F. A. Deviney, J. N. Galloway, C. A. Rinehart, P. A. Thompson, and S. Wilson. 1994. The acid-base status of native brook trout streams in the mountains of Virginia. Department of Environmental Sciences, University of Virginia, Charlottesville, Virginia.

Whitmore, C. M., C. E. Warren, and P. Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Transactions of the American Fisheries Society 89:17-26.

Woodward, D. F., A. M. Farag, M. E. Mueller, E. E. Little, and F. A. Vertucci. 1989. Sensitivity of endemic Snake River cutthroat trout to acidity and elevated aluminum. Transactions of the American Fisheries Society 118:630-643.

Table 5C-1. Number of brook char and blacknose dace observed over 30 experimental trials among zones, percent use by zone throughout the trials, and % deviation from control within a laboratory stream after introduction of food and acid water.

	Experimental Zones					
	Near		Distance from Input		Far	
	1	2	3	4	5	6
Brook char						
# fish observed	0.03	0.14	0.57	4.22	2.81	7.23
percent use	0.2	0.9	3.8	28.1	18.8	48.2
% deviation	-41.3	-21	-20.9	21.7	14	47.5
Blacknose dace						
#fish observed	0.01	0.35	2.03	9.43	1.80	1.38
percent use	0.1	2.3	13.5	62.9	12	9.2
% deviation	-3.9	-44	-23.1	52.1	10.4	8.5

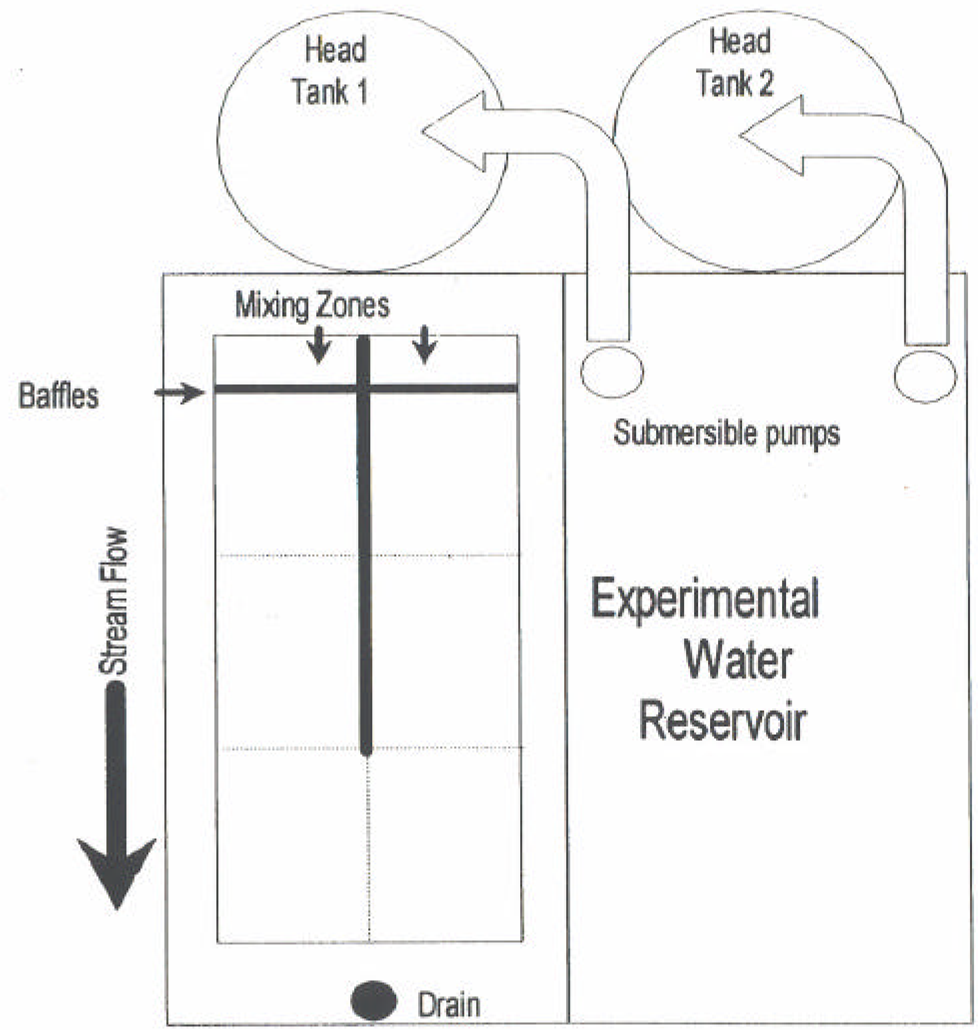


Figure 5C-1. Schematic diagram of laboratory stream used to test avoidance behavior of broo char and blacknose dace to low pH.

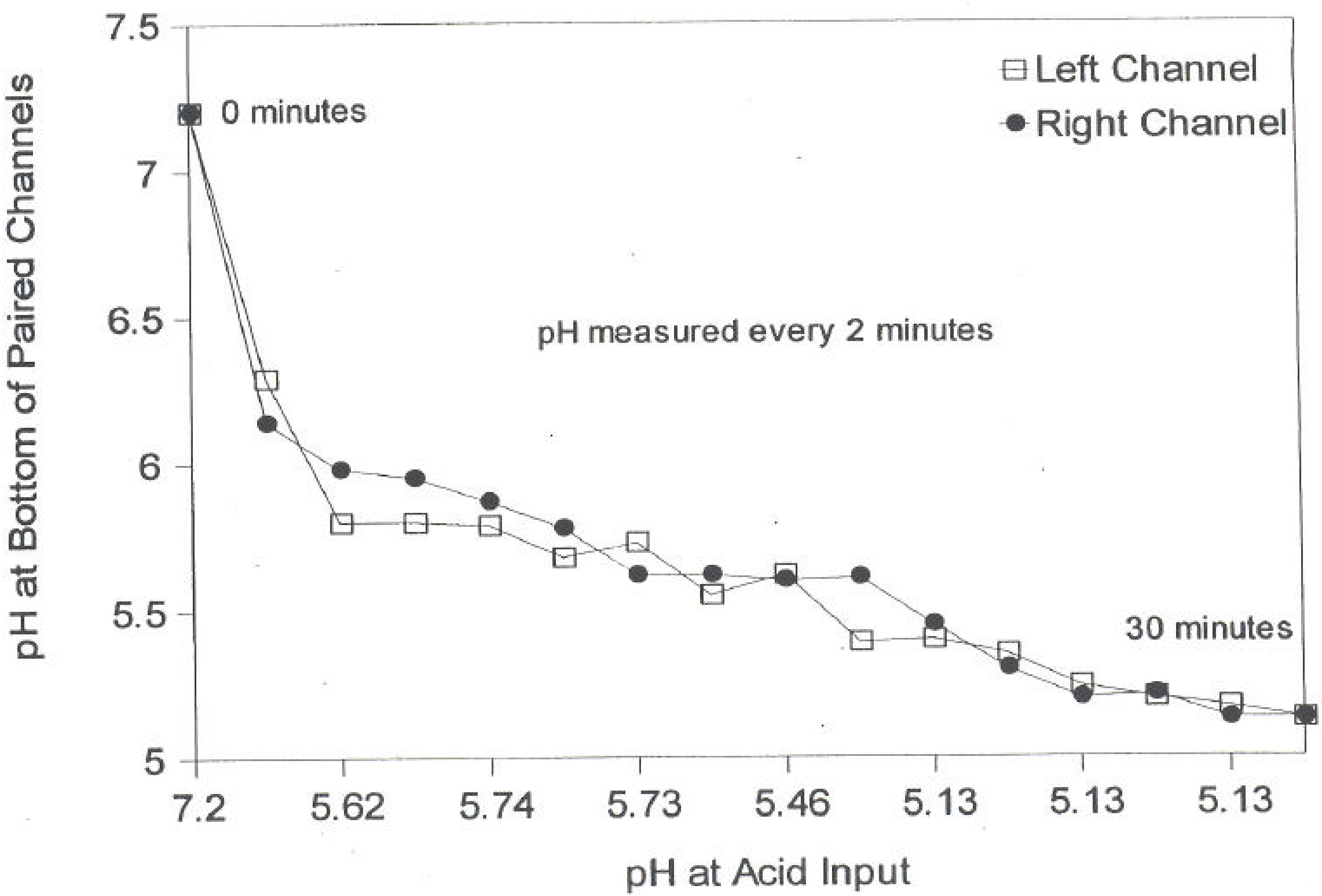


Figure 5C-2. Relationship between pH at the head of the channels (acid input), and the tail of the channels (experimental water exit) for the duration of an experimental trial.

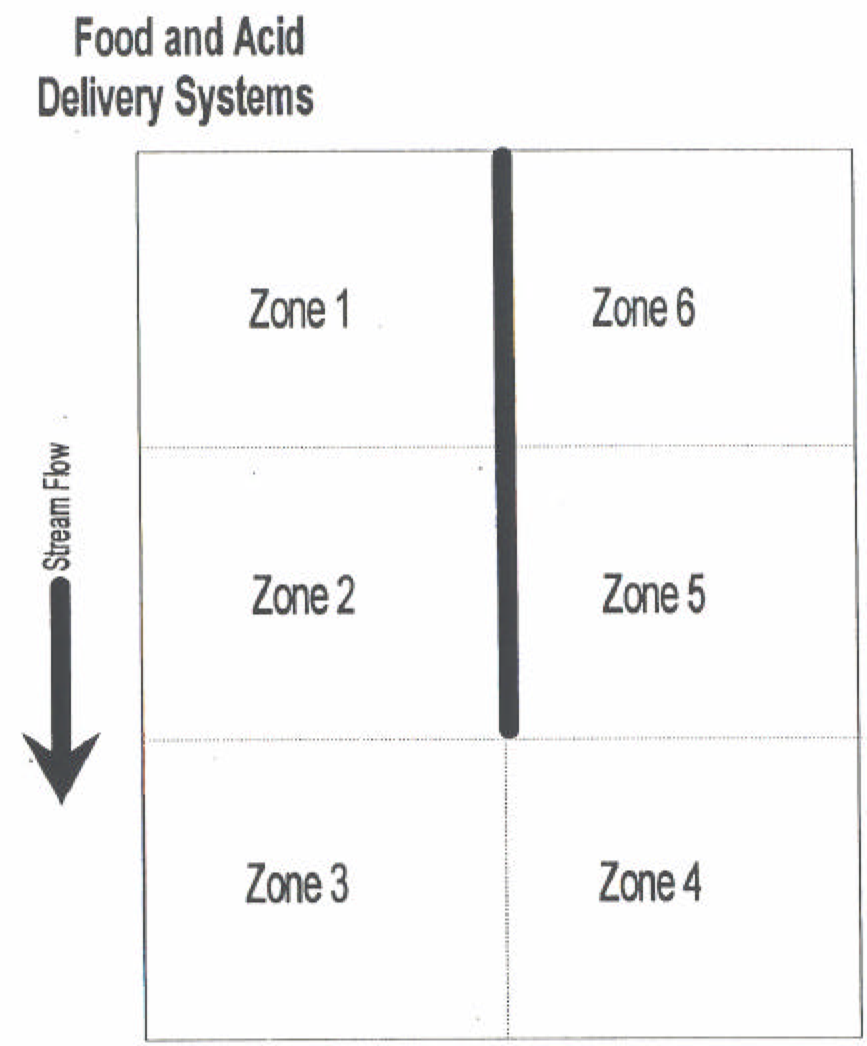
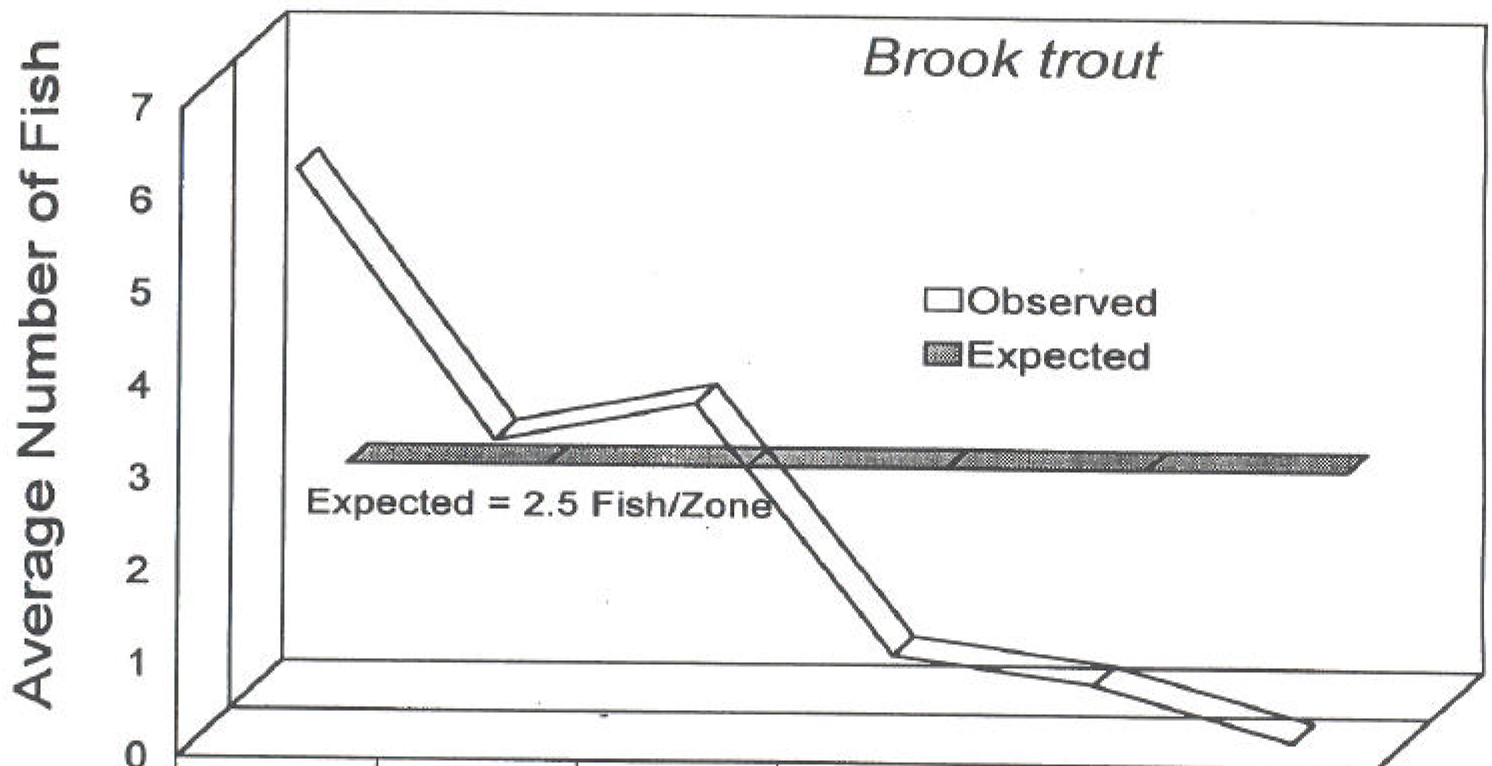


Figure 5C-3. Schematic diagram depicting relationship between food and acid delivery point and experimental zones within laboratory stream channels.



	1	2	3	4	5	6
Observed	6.2	3.3	3.7	1	0.7	0.1
Percent	41.5	21.9	24.7	6.4	4.8	0.7

Figure 5C-4. Average number of brook char over 30 experimental trials among zones within a laboratory stream after food introduction. Zone one was nearest and zone 6 furthest from the input

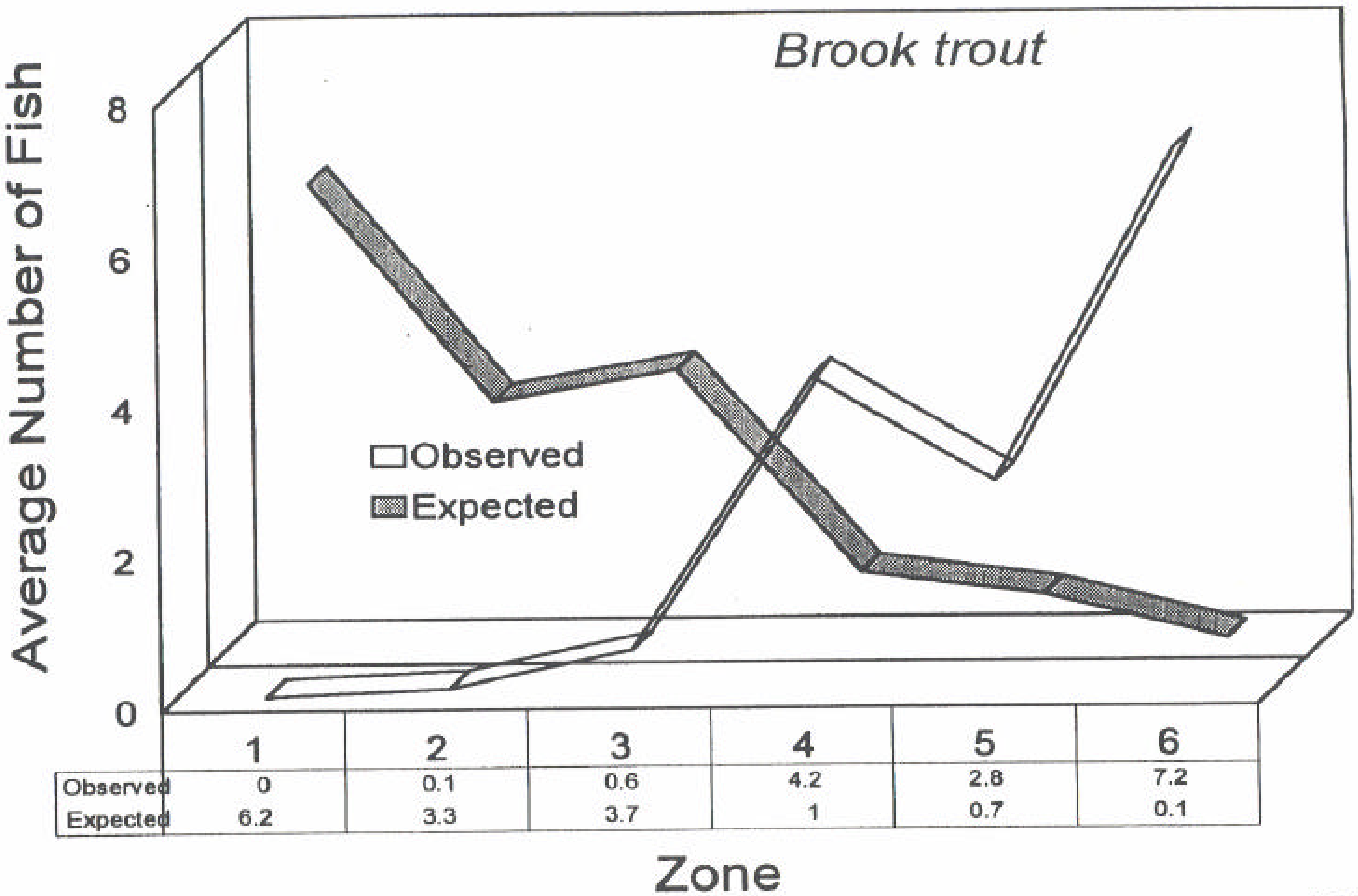
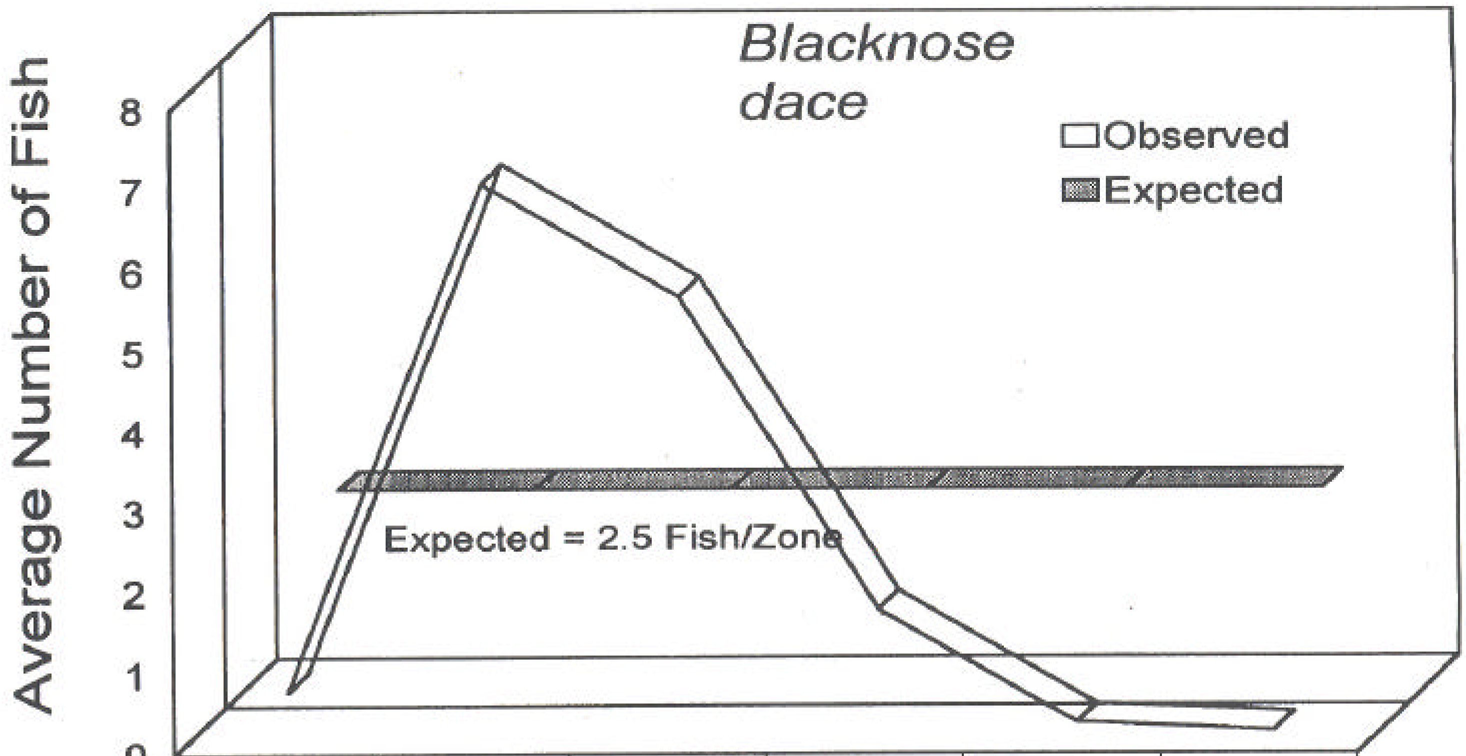


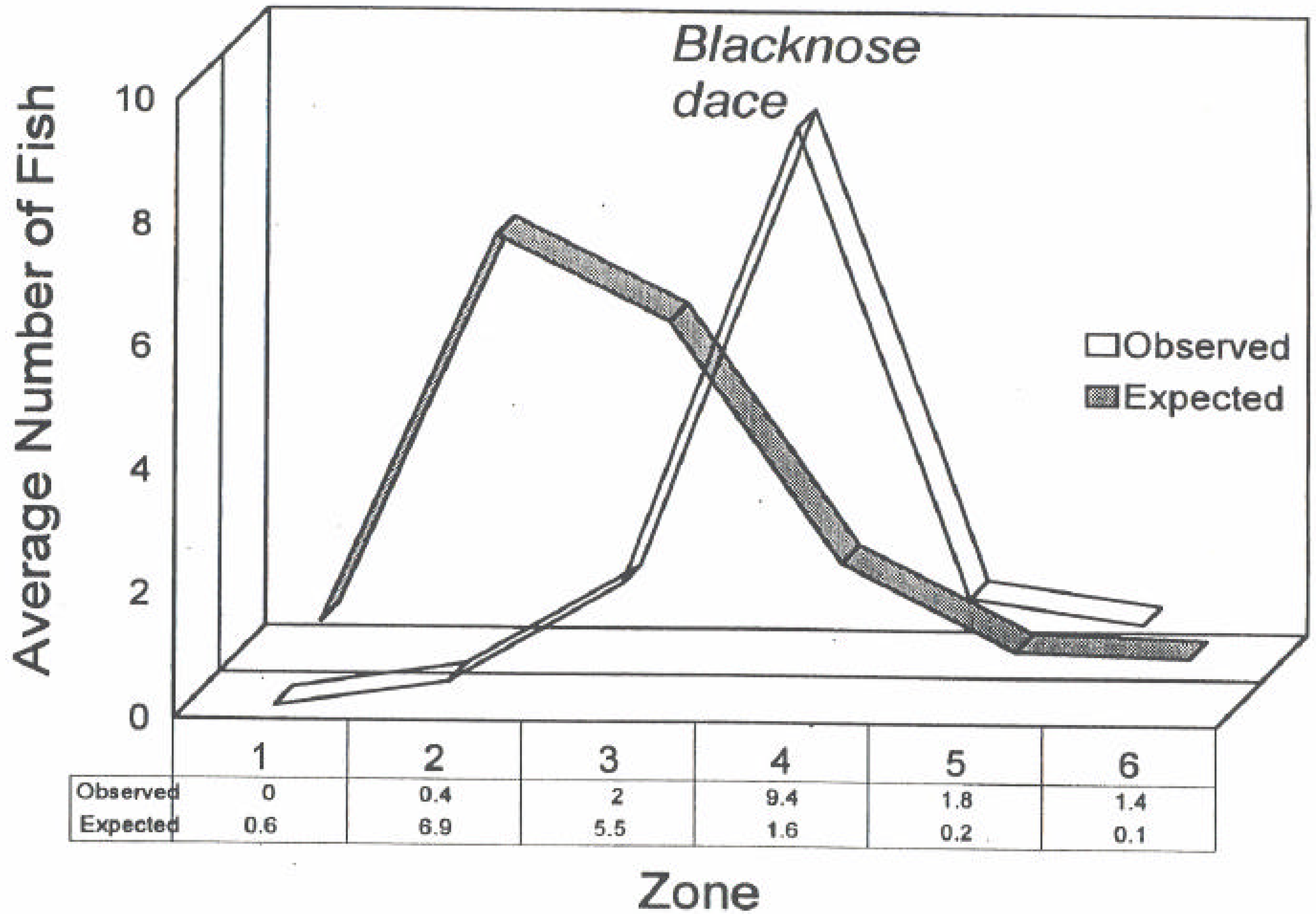
Figure 5C-5. Average number of brook char over 30 experimental trials among zones within the laboratory stream after food introduction (expected), and after introduction of food and acid (observed). Zone one was nearest and zone 6 furthest from the input.



	1	2	3	4	5	6
Observed	0.6	6.9	5.5	1.6	0.2	0.1
Percent	4	46.3	36.6	10.8	1.6	0.7

Zone

Figure 5C-6. Average number of blacknose dace over 30 experimental trials among zones of a laboratory stream after food introduction. Zone one was nearest and zone 6 furthest from the input



	1	2	3	4	5	6
Observed	0	0.4	2	9.4	1.8	1.4
Expected	0.6	6.9	5.5	1.6	0.2	0.1

Figure 5C-7. Average number of blacknose dace brook char over 30 experimental trials among zones within the laboratory stream after food introduction (expected), and after introduction of food and acid (observed). Zone one was nearest and zone 6 furthest from the input.

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Chapter 5D

Extensive Inventory of Physical Habitat and Fish Populations in Five Streams with Different Acid Neutralizing Capacities in Shenandoah National Park, Virginia

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Abstract

We used a combination of visual estimates and more precise measurements to estimate habitat and fish populations in five Shenandoah National Park, Virginia watersheds ranging in ANC from low (3 basins) to moderate (2 basins). All habitats from the SNP boundary to the upper extent habitable by fish were inventoried. Fish community composition was comprized of two to four species and included brook char (*Salvelinus fontinalis*), blacknose dace (*Rhinichthys atratulus*), American eels (*Anguilla rostrata*), and fantail darters (*Etheostoma flabellare*). Brook char and blacknose dace were the only species common to all five watersheds.

Introduction

Shenandoah National Park (SNP), located in the northern region of the Blue Ridge Province, has the greatest loading of sulfate of any National Park in the United States (Webb et. al 1989). As a direct result, streams in some SNP watersheds have become subject to episodic and chronic acidification.

Numerous studies have demonstrated that increased acidification of stream water can have a negative effect on aquatic fauna. Acidification poses a particular threat to the existence of species such as brook trout (*Salvelinus fontinalis*) which in the southeastern United States are largely confined to headwater streams in the Southern Appalachian Mountains (Neves and Pardue 1983; Jenkins and Burkhead 1994),.

The purpose of this study was to characterize the habitat and populations of fish living in eight SNP watersheds affected to varying degrees by acidic deposition. It was part of a long-term monitoring program designed to document trends in acidification and identify specific watersheds where acidification poses particular risks to species and species assemblages. Habitat, water chemistry, and fish populations were the focus of studies in three of the eight basins, with varying levels of acid neutralizing capacity (ANC), Paine Run-low, Staunton River-moderate, Piney River-high. The five additional basins, ranging in ANC from low (3 basins) to moderate (2 basins), constituted the core for an extensive survey of habitat conditions and fish populations.

We used a combination of visual estimates and more precise measurements to estimate habitat and fish populations (Dolloff et al. 1993) by sampling habitats from the SNP boundary to the upper extent habitable by fish in the five watersheds.

Methods

Habitat survey

We used the basinwide visual estimation technique (BVET) to inventory habitat and fish populations in each basin during the summer of 1994 (June - August). All main branches were surveyed by the same two-person crew starting at the SNP boundary or at a confluence with another stream. Tributaries were surveyed only if they had sufficient water to support fish, as determined on site by the sampling crew. Surveys were concluded when, in the opinion of the crew leader, habitat became unable to support fish. In practice, this occurred when the stream emerged from underground or simply “went dry.”

Data collected included habitat unit type, length, mean wetted channel width, mean bankfull channel width, maximum and mean depth, substrate composition (dominant and subdominant), and number of pieces of large woody debris (LWD) in different size categories.

Habitat types were limited to pools and riffles following descriptions by Bisson et. al (1982). Substrate was assigned to one of nine size classes, the dominant-covering the major percentage of the bottom of a selected habitat, and subdominant-covering the second highest percentage of the bottom, were identified and recorded in each habitat unit. The number of LWD pieces in each of seven size classes were recorded along with other significant features that were suspected to influence fish populations (e.g. landslides, tributary junctions, bridge and trail crossings, and major changes in riparian vegetation).

Fish population survey

We determined the sampling fraction (relative proportions of habitat units by habitat type) before each sampling period according to a stratified random design based on the size and location of habitat units in the drainage and their perceived importance to fish. Each habitat unit was numbered in sequence beginning at the downstream end of each sampled reach, and random numbers were chosen as the starting points for selection of units for measurement. A typical sequence included every 5th (20%) pool and every 10th (10%) riffle. In smaller reaches every 3rd (33%) pool and every 5th (20%) riffle were sampled to account for natural variation.

Fish populations were censused by divers equipped with face mask, snorkel, and writing slate. Divers carefully entered each selected habitat unit and recorded the species, numbers, and relative size (i.e. age 0+, 1+, and 2+ for brook trout) of all fish observed. After completing the observations in a habitat unit, the recorder attached an identifying flag in a conspicuous location to be referenced during the next phase of population sampling.

After the underwater observations were completed in the sub basin, we selected a fraction (about 10%) of the total number of units snorkeled in which to conduct a multiple-pass removal census (Zippen 1958) with a backpack electroshocker (700V AC) and dip nets. All fish were identified, measured (fork and total length ($\pm$1.0 mm)), and weighed ($\pm$0.1 g) before being returned to their approximate location of capture. Electrofishing was essential for two reasons: (1) to verify identifications and counts made by divers; and, (2) to obtain accurate measurements of length and weight.

Total lengths of fish were used to calculate length frequencies for blacknose dace and brook trout. Population estimates for each species (including age 0+ brook trout) were calculated, and diver counts of fish number per unit of habitat area (density) were averaged by habitat types to obtain estimates of density for each reach. Reach lengths used for calculating densities were truncated at the limits of fish distribution. The distribution for each species encompassed habitat where individuals of a certain species were first observed to where they were last seen by a diver in each reach.

Data were entered and the results compiled and summarized using Quattro Pro, Sigma Plot, Harvard Graphics, Presentations, Microfish, and PC-SAS computer packages.

Study Sites

All five watersheds lie within the SNP boundary (Figure 5D-1), and eventually flow into the Atlantic Ocean via either the Shenandoah (Potomac) or Rappahannock Rivers. They are presented in this report in theorder that they were surveyed: Brokenback Run, White Oak Run, Shaver Hollow, Twomile Run, and Meadow Run.

Second-order Brokenback Run (moderate ANC), located in the Central District of SNP near Old Rag Mountain, flows east from an elevation of 840 meters over mostly granitic bedrock to its confluence with the Hughes River just outside the SNP boundary. First-order tributary Weakley Hollow flows into Brokenback Run about 1.8 kilometers upstream of the Park boundary from an elevation of 510 meters. This is the only watershed of the extensive survey in the Rappahannock River System.

Second-order White Oak Run (low ANC), located in the South District of SNP, flows west from an elevation of 730 meters over silica-clastic bedrock to its confluence with Madison Run inside the SNP boundary. From an elevation of 700 meters, first-order Luck Hollow drains into White Oak Run about 1.3 kilometers upstream of its confluence with Madison Run.

In the Central District of SNP, moderately sensitive first-order Shaver Hollow flows west from an elevation of 700 meters over mostly granitic bedrock to a tributary confluence at the beginning of the North Fork of Dry Run.

Second-order Twomile Run (low ANC), located in the South District of SNP, flows west from an elevation of 670 meters over mostly silica-clastic bedrock, to its confluence with the Shenandoah River outside the Park boundary. An unnamed first order tributary flows into Twomile Run about 1.4 kilometers from the downstream boundary of SNP.

Second-order Meadow Run (low ANC), located in the South District of SNP, also is considered highly sensitive to episodic acidification. Surface water in Meadow Run flows west from an elevation of 730 meters over silica-clastic bedrock before it goes subterranean about 2 kilometers above the South River. Three first-order tributaries of Meadow Run were included in the survey. Wildcat Hollow, the largest tributary, flows into Meadow Run 1.5 kilometers upstream from the SNP boundary. An unnamed tributary flows into the main branch about 300 meters above Wildcat Hollow. Cold Spring Hollow, a spring-fed tributary, drains into Meadow Run approximately 2.9 kilometers upstream from the Park boundary. Both Wildcat Hollow and the unnamed tributary begin at elevations of 730 meters, and Cold Spring Hollow starts at an elevation of 670 meters.

Results

Because conditions (e.g. general weather patterns) did not change following the inventory of habitat features in each basin, physical habitat was assumed constant for fish sampling.

Brokenback Run

We inventoried 354 pools and 323 riffles in over 6 kilometers of Brokenback Run including the main branch and one tributary, Weakley Hollow. Total habitat area for the main branch ranged from 5,181 m^2 for pools to 6,566 m^2 for riffles (Table 5D-1.). Total habitat area in Weakley Hollow for riffles was twice the amount in pools (Table 5D-1). Bankfull area for the main branch was the highest of all five watersheds (Table 5D-2.).

Mean maximum and mean average depths in both pools and riffles was higher in Brokenback Run than in any of the other five basins (Figures 5D-2a,b). Among all tributaries, Weakley Hollow had the highest mean maximum and mean average depth for riffles and was second highest for pools (Figure 5D-3a,b).

Substrate class dominance varied considerably in the main branch, with all classes represented except clay. The most common substrate classes were bedrock, cobble, and boulder in ascending order (Figure 5D-2c.). In Weakley Hollow, the most frequent dominant substrates were boulder, sand, and silt (Figure 5D-3c.).

The LWD in the active channel of the main branch and the tributary mostly consisted of two smallest size classes (Figures 5D-2d and 5D-3d). However, a significant number of root wads (size class 7) were present in the main branch.

Three fish species were found in the Brokenback Run basin: brook char, blacknose dace (*Rhinichthys atratulus*), and American eel (*Anguilla rostrata*). We were not able to calculate population estimates for American eels because none were seen by divers and only two individuals were found in our electrofishing survey. Brook trout were the only salmonid found in Brokenback Run even though the state of Virginia currently stocks rainbow trout (*Oncorhynchus mykiss*) less than one mile downstream from the SNP boundary in the Hughes River. Adult and young-of-the-year brook trout were present throughout both the main branch and the tributary (Figures 5D-4a and 5D-5).

Based on Analysis of length frequencies, three year classes of brook trout were present in Brokenback Run with age 1+ fish being the most prevalent. Age 0+ brook trout were present but not well represented (Figure 5D-4b). Numbers of adults in the main branch ranged from 602 in riffles to 941 in pools (Tables 5D-3 and 5D-4). Densities of young-of-the-year brook trout were lower than adult densities in the main branch (Figure 5D-4c). Population estimates for adult brook trout were significantly higher than young of the year estimates in Weakley Hollow (Tables 5D-5 and 5D-6).

We observed a typical bi-modal distribution of size classes for blacknose dace (e.g., two year classes) (Figure 5D-4d); dace spawn from spring through summer and typically live two years. When we surveyed Brokenback Run, in the first week of June, the nuptial males were brightly colored, indicating they were in spawning condition. In concurrence with Jenkins and Burkhead (1994), we noted that the markings and coloration of blacknose dace from this upper Rappahannock tributary differed from the other four basins.

Blacknose dace population estimates ranged from 180 in riffles to 333 in pools for the main branch (Tables 5D-3 and 5D-4). Because blacknose dace were not seen by divers or captured by electrofishing above 1960 meters (Figure 5D-4a) densities were calculated only for the section from the SNP boundary upstream to 1960 meters (Figure 5D-4c). Blacknose dace were not present in Weakley Hollow which flows into the main branch well within their main branch distribution.

White Oak Run

We surveyed habitat in over 5 kilometers of White Oak Run including one major tributary, Luck Hollow. The stream bed of White Oak Run was mostly dry from the confluence of White Oak Run and Madison Run upstream about 500 meters. Only a few large bedrock pools contained water in the lower section. Near the top of White Oak Run we encountered a large waterfall (at least 8 meters tall) above which habitat consisted of a long shallow riffle (less than 5 centimeters in depth) that went underground after approximately 350 meters. In total there were 205 pools and 184 riffles in White Oak Run. Estimated area for the main branch ranged from 2,300 m^2 for pools to 2,522 m^2 for riffles. Lower Luck Hollow also was dewatered for about 700 meters. But as in main White Oak Run, habitat quality improved upstream. Estimated areas in Luck Hollow for both habitat types were very low because of the amount of dewatered area (Table 5D-1). Bankfull estimates for White Oak Run and Luck Hollow are 14,008 m^2 and 4,793 m^2 respectively (Table 5D-2).

Because of the dry conditions in White Oak Run the mean maximum and mean average depths for the main branch and Luck Hollow were relatively low compared to the other four basins (Figures 5D-6a,b and 5D-7a,b).

Substrate classes consisted of small gravel, large gravel, cobble, boulder, and bedrock in both the main branch and Luck Hollow. (Figures 5D-6c and 5D-7c). Most of the LWD was size class 1 in White Oak Run and Luck Hollow (Figures 5D-6d and 5D-7d).

Diversity of fish species in White Oak Run was higher than in three of the other streams; brook trout and blacknose dace were present along with fantail darters (*Etheostoma flabellare*), which were only present in White Oak Run.

Brook trout were present to within 200 meters of the waterfall (3,100 meters elevation; Figure 5D-8a). We did not sample above the waterfall but assumed fish were not present because of the height of the waterfall and the lack of habitat above it. Brook trout were observed by divers in Luck Hollow, but in very low numbers.

Length frequency analysis for brook trout showed that age 0+, and age 1+ fish were well represented in White Oak Run, but age 2+ fish were not (Figure 5D-8b). Population estimates and densities of adult brook trout were higher than in any of the other four basins (Tables 5D-7 and 5D-8 ; Figure 5D-8c).

We found blacknose dace in the main branch up nearly as far as brook trout (Figure 5D-8a). We did not observe or electrofish blacknose dace in Luck Hollow.

Both year classes of blacknose dace were well represented (Figure 5D-8d). Blacknose dace population estimates and densities were among the highest (Twomile Run had the highest) in the five basins (Tables 5D-7 and 5D-8 ; Figure 5D-8c).

Fantail darters apparently were confined to about 1300 meters in the lower reaches of White Oak Run. Fantail darters were neither seen by divers or captured by electrofishing above Luck Hollow (Figure 5D-8c). Fantail darter densities were higher in riffles than in pools (Figure 5D-8c).

Shaver Hollow

We inventoried 90 pools and 76 riffles in over 1.6 kilometers of Shaver Hollow, from the SNP boundary up to where the stream went completely dry and split into two forks. The stream had moderate flows up to the one kilometer mark, after which there were sections of dry stream bed interspersed with standing pools. There also were two steep cascades, one at 780 meters and the other at 912 meters. Total habitat area ranged from 709 m^2 for pools and 878 m^2 for riffles (Table 5D-1). The bankfull habitat area estimate for Shaver Hollow was 6,948 m^2 (Table 5D-2).

The mean maximum and mean average depths for Shaver Hollow are shown in Figures 5D-9a and b for both pools and riffles. Dominant substrate was primarily cobble, boulder, and bedrock (Figure 5D-9c). Once again, the smallest size class of LWD was most common; however there were significant numbers of the larger diameter size pieces (size classes 5 and 6) (Figure 5D-9d).

We found only brook trout and blacknose dace in Shaver Hollow; no fish were found in any of the sample units above the waterfall located at 780 meters (Figure 5D-10a).

Three year classes of brook trout were present in Shaver Hollow (Figure 5D-10b), with age 1+ fish comprising the bulk of the population. However, Shaver Hollow had proportionally large numbers of age 2+ fish compared to the other four basins. In addition, four of eight brook trout caught in pool 54 (pool below waterfall) were greater than 225 mm TL. One of those fish was 271 mm TL and weighed over 200 grams. Population estimates for adult brook trout in Shaver Hollow were significantly higher in pools than in riffles, and population estimates for young of the year fish were very low (Tables 5D-9 and 5D-10). Densities for both cohorts of brook trout in Shaver Hollow are similar to the population estimates (Figure 5D-10c). Densities for both fish species were calculated using only the habitat area below the waterfall at 780 meters.

Both year classes of blacknose dace were present in Shaver Hollow (Figure 5D-10d). Population estimates for blacknose dace in Shaver Hollow range from 309 fish in pools to 49 fish in riffles (Tables 5D-9 and 5D-10). Densities for Shaver Hollow ranged from 91 fish per 100 m^2 in pools to 12 fish per 100 m^2 in riffles (Figure 5D-10c).

Twomile Run

We surveyed a total of 222 pools and 181 riffles in over 5 kilometers of the main branch, one unnamed tributary, and the upper right fork of Twomile Run. Total area in Twomile Run was 3,472 m^2 for pools an 3,799 m^2 for riffles (Table 5D-1). Estimated areas in the right fork and the unnamed tributary were very low because of low water level (Table 5D-1). Bankfull area for the main branch of Twomile Run was 19,483 m^2, while the bankfull areas for the right fork and the tributary were 1,470 m^2 and 1,229 m^2 respectively (Table 5D-2). The mean maximum and mean average depths for the main branch were similar to depths found in White Oak Run (Figure 5D-11a and b) .

Dominant substrates in the main branch of Twomile Run consisted mostly of small gravel and larger size classes with bedrock and cobble the most frequently observed (Figure 5D-11c). Most of the LWD found in Twomile Run was less than 10 cm in diameter (size classes 1 and 4) (Figure 5D-11d).

The fish assemblage in Twomile Run consisted of brook trout and blacknose dace. Most of the fish were found in the main branch, with very few fish in the tributary and the right fork. Brook trout and blacknose dace were observed in the first 100 meters of the tributary, and one brook trout was seen during the habitat survey in the lower part of the right fork. Adult brook trout were found throughout the watershed, and brook trout young-of-the-year were only found from the park boundary up to the confluence of the tributary and the main branch (Figure 5D-12a). All three year classes of brook trout were present in Twomile Run (Figure 5D-12b). Age 0+ fish were well represented considering that they were only found in the lower sections. Age 1+ fish are not very numerous in Twomile Run and the age 2+ fish were represented by a single individual captured during electrofishing.

The population estimate for adult brook trout in pools was 675 fish (Table 5D-11). No adult brook trout were present in riffles. Population estimates for young-of-the-year brook trout in the main branch were 329 fish in pools and 139 fish in riffles (Table 5D-11 and 5D-12).

Densities for brook trout were 20 fish per 100 m^2 for adults in pools, 22 fish per 100 m^2 for young-of-the-year in pools, and 9 per 100 m^2 for young of the year in riffles (Figure 5D-12c). Densities for age 0+ brook trout were calculated using area only up to where they were observed and captured.

Blacknose dace in Twomile Run extended further upstream than brook trout (Figure 5D-12a). Two age classes of blacknose dace were present in Twomile Run (Figure 5D-12d). Population estimates and densities for blacknose dace in pools were the highest of all five main branches surveyed (Table 5D-11; Figure 5D-12c).

Meadow Run

We surveyed habitat in nearly 9 kilometers of Meadow Run, including the main branch, right fork, Cold Spring Hollow, an unnamed tributary, and Wildcat Hollow. Major habitat summaries were done only for the main branch, Wildcat Hollow, and the unnamed tributary because the remainder were not habitable by fish at the time of the survey. A total of 459 pools and 406 riffles were surveyed. The majority of the area consisted of riffle habitat (Table 5D-1). Bankfull area estimates for Meadow Run ranged from 715 m^2 in the right fork to 25,219 m^2 in the main branch (Table 5D-2).

The mean maximum and mean average depths for the main branch were relatively high compared to the other watersheds even though it was sampled in August (Figures 5D-13a and b). Water depths in the unnamed tributary (Figures 5D-14a and b), and Wildcat Hollow (Figures 5D-15a and b) were comparable to depths in the main branch.

Dominant substrate consisted primarily of small gravel, large gravel, cobble, and boulder in the main branch of Meadow Run, with smaller amounts of silt, bedrock, and organic matter (Figure 5D-13c). Substrate dominance in the unnamed tributary and Wildcat Hollow was similar, with both exhibiting silt and organic matter as a dominant substrate more frequently than the main branch (Figures 5D-14c and -15c).

LWD, as in all the other basins, was made up of mostly the smaller diameter pieces (e.g. size classes 1 and 4) in the main stem (Figure 5D-13d), the unnamed tributary (Figures 5D-14d), and Wildcat Hollow (Figure 5D-15d). We found an old stream structure, consisting of five or six railroad ties laid perpendicular to the stream channel, in a riffle immediately below the confluence of Cold Spring Hollow and Meadow Run at 2,831 meters. The ties were spaced about 1 m apart and were attached to the predominately bedrock substrate with steel reinforcing rod.

Brook trout were common throughout the basin while blacknose dace were very rare. Brook trout young-of-the-year and adults were widely and abundantly distributed in both the main branch and Wildcat Hollow (Figures 5D-16a and 5D-17a). No fish were seen by divers in Cold Spring Hollow or the right fork. However, a large adult brook trout was seen in a pool on the right fork during the habitat survey.

All three age classes were present in Meadow Run (Figure 5D-16b), where age 0+ fish accounted for approximately 80% of the brook trout. Meadow Run had more young-of-the-year brook trout than any of the four other basins (Tables 5D-13 and 5D-14). Density of brook trout in pools of the main branch ranged from 16 fish per 100 m^2 for adults to 35 fish per 100 m^2 for young of the year (Figure 5D-16c).

We captured 36 brook trout in 10 units during the electrofishing survey in Wildcat Hollow. Population estimates for young-of -the-year in Wildcat Hollow were significantly higher than estimates in all other tributaries surveyed (Tables 5D-15 and 5D-16; Figure 5D-17b).

Divers sampled units throughout the unnamed tributary and saw 26 brook trout young-of-the-year in a pool 24 m above the starting point but no place else. Although we electrofished eight habitat units selected at random throughout the tributary (not including the previously mentioned pool), we captured no fish. The gradient of this unnamed tributary was very steep for at least the first 350 meters which is the likely reason no fish were seen above the pool at 24 m.

In the main branch only a few blacknose dace were observed by divers (6 and 2 fish in two different pools) and only two were captured in the electrofishing survey (both > 55 mm, total length). No blacknose dace were found in any of the tributaries of Meadow Run.

Miscellaneous Observations

1) The higher depths in Brokenback Run could be attributed to many things such as: stream discharge on the date of survey, drainage size, underlying geology, historical uses, and adjacent land use.

2) The population estimate for adult brook trout in White Oak Run was the highest for the five main branches. These results conflicted with our expectations: White Oak Run, because of chronically low ANC, is considered the most acid sensitive of the eight basins surveyed in SNP (Webb et al. 1989).

3) Brook trout were distributed further upstream than blacknose dace in all eight basins except for Twomile Run.

4) We counted 25 young-of-the-year brook trout, 28 adult brook trout, and 57 blacknose dace in one large pool approximately 175 meters from the lower SNP boundary of Twomile Run. On more than one occasion (within a week) we observed this pool used as a swimming hole. There was a lot of trash in the proximity. On the second day of the survey, a thunder storm the previous night caused a large tree with numerous branches to fall into the pool. By evening of the same day the tree had been removed from the water and all the branches and most of the trunk had been trimmed with a chain saw.

5) Although Twomile Run was closed to fishing at the time of the survey, two adult brook trout captured by electrofishing a pool about 650 meters upstream from the SNP boundary had obvious hook injuries on their jaws.

References

Bisson, P.A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 67-73 *In* N.B. Armantrout editor. Acquisition and Utilization of Aquatic Habitat Inventory Information. Western Division, American Fisheries Society, Portland, Oregon.

Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993. Basinwide estimation of habitat and fish populations in streams. General Technical Report SE-83. Asheville, North Carolina: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 pp.

Jenkins, R. E., and N. M. Burkhead. 1994. Freshwater fishes of Virginia. American Fisheries Society. Bethesda, Maryland. 1079 pages.

National Academy of Sciences. 1986. Acid Deposition Long-Term Trends. National Academy Press, Washington D. C.

Neves, R. J., and G. B. Pardue. 1983. Abundance and production of fishes in a small Appalachian stream. Transactions of the American Fisheries Society 112: 21-26.

Newman, K. R. 1995. Response of brook char (*Salvelinus fontinalis*) and blacknose dace (*Rhinichthys atratulus*) to acidic episodes in three headwater streams within the Shenandoah National Park, Virginia. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Webb, J. R., B. J. Cosby, J. N. Galloway, and G. M. Hornberger. 1989. Acidification of native brook trout streams in Virginia. Water Resources Research 25 (6): 1367-1377.

Zippen, C. 1958. The removal method of population estimation. Journal of Wildlife Management. 22: 82-90.

Table 5D-1. Estimates of total habitat area for streams in five SNP watersheds.

Stream Reach	Distance (meters)	Habitat Type	Est. Area (m^2) ($\pm$95%CI)
Brokenback Run	4,892.9	Pools	5,181(262)
		Riffles	6,566(475)
Weakley Hollow	1,169.3	Pools	499(29)
		Riffles	1,063(36)
White Oak Run	3,552.5	Pools	2,300(64)
		Riffles	2,522(68)
Luck Hollow	1,712.2	Pools	142(18)
		Riffles	455(22)
Shaver Hollow	1,652.7	Pools	709(23)
		Riffles	878(51)
Twomile Run	4,161.8	Pools	3,472(106)
		Riffles	3,799(207)
Twomile Right Fork	499.2	Pools	47(1)
		Riffles	134(12)
Twomile Tributary	552.4	Pools	100(8)
		Riffles	135(7)
Meadow Run	5,391.3	Pools	4,499(113)
		Riffles	7,459(352)
Wildcat Hollow	1,627.1	Pools	585(54)
		Riffles	1,408(116)
Unamed Tributary	878.3	Pools	446(19)
		Riffles	513(42)
Cold Spring Hollow	495.2	Pools	204(23)
		Riffles	376(23)
Meadow Run Right Fork	385.7	Pools	40(16)
		Riffles	155(61)

Table 5D-2. Estimates of bankfull channel area for streams in five SNP watersheds.

Stream Reach	Distance (meters)	Bankfull Area (m^2) ($\pm$95% CI)
Brokenback Run	4,892.9	29,722(648)
Weakley Hollow	1,169.3	4,484(212)
White Oak Run	3,552.8	14,008(350)
Luck Hollow	1,712.2	4,793(59)
Shaver Hollow	1,652.7	6,948(271)
Twomile Run	4,161.8	19,483(409)
Twomile Right fork	499.2	1,470(36)
Twomile Tributary	552.4	1,229(70)
Meadow Run	5,391.3	25,219(1,739)
Wildcat Hollow	1,627.1	4,985(124)
Unnamed Tributary	878.3	2,801(92)
Cold Spring Hollow	495.2	1,073(79)
Meadow Right fork	385.7	715(75)

Table 5D-3. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in pools of Brokenback Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	1.42	0.22	0.37
$\hat{N}$ (± 95% CI)	941 (338)	105 (33)	333 (169)
Mean Total Length (± 95% CI)	158 (12)	60 (1)	76 (6)
Mean Weight (± 95% CI)	43.0 (7.7)	2.3 (0.8)	5.9 (1.2)

[1] 58 pools were snorkeled and 10 pools were electrofished.

Table 5D-4. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in riffles of Brokenback Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	4.10	0.52	0.80
$\hat{N}$ (± 95% CI)	602 (328)	140 (55)	180 (192)
Mean Total Length (± 95% CI)	142 (9)	64 (3)	68 (9)
Mean Weight (± 95% CI)	35.5 (8.4)	3.3 (0.7)	4.8 (1.9)

[1] 27 riffles were snorkeled and 10 riffles were electrofished.

Table 5D-5. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in pools of Weakley Hollow.

Species	Adult brook trout	Young-of-year brook trout
Calibration ($\hat{R}$)[1]	4.00	1.00
$\hat{N}$	168	21
(± 95% CI)	(127)	(21)
Mean Total Length	125	50
(± 95% CI)	(12)	(0)
Mean Weight	23.2	1.7
(± 95% CI)	(2.7)	(0.0)

11 pools were snorkeled and 4 pools were electrofished.

Table 5D-6. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in riffles of Weakley Hollow.

Species	Adult brook trout	Young-of-year brook trout
Calibration ($\hat{R}$)[1]	1.00	1.00
$\hat{N}$	11	0
(± 95% CI)	(41)	(0)
Mean Total Length	118	NA
(± 95% CI)	(0)	
Mean Weight	18.4	NA
(± 95% CI)	(0.0)	

6 riffles were snorkeled and 3 riffles were electrofished.

Table 5D-7. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), and mean total length and weight for all fish species in pools of White Oak Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace	Fantail darters
Calibration ($\hat{R}$)[1]	5.00	0.67	1.35	0.64
$\hat{N}$ (± 95% CI)	2,217 (559)	95 (52)	2,171 (1132)	52 (137)
Mean Total Length (± 95% CI)	131 (6)	56 (0)	56 (3)	51 (6)
Mean Weight (± 95% CI)	26.0 (2.3)	2.0 (0.0)	2.1 (0.5)	1.9 (0.9)

[1] 37 pools were snorkeled and 10 pools were electrofished.

Table 5D-8. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), and mean total length and weight for all fish species in riffles of White Oak Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace	Fantail darters
Calibration ($\hat{R}$)[1]	1.00	1.64	6.38	1.21
$\hat{N}$ (± 95% CI)	15 (24)	52 (147)	1235 (540)	256 (181)
Mean Total Length (± 95% CI)	121 (16)	69 (4)	52 (3)	59 (4)
Mean Weight (± 95% CI)	20.0 (10.9)	3.7 (0.8)	1.7 (0.2)	2.3 (0.1)

31 riffles were snorkeled and 10 riffles were electrofished.

Table 5D-9. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), and mean total length and weight for
all fish species in pools of Shaver Hollow.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	3.00	0.50	0.61
$\hat{N}$ (± 95% CI)	270 (110)	21 (27)	309 (147)
Mean Total Length (± 95% CI)	160 (14)	69 (3)	61 (3)
Mean Weight (± 95% CI)	48.9 (16.0)	3.8 (1.8)	2.5 (0.4)

26 pools were snorkeled and 11 pools were electrofished.

Table 5D-10. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), and mean total length and weight for all fish species in riffles of Shaver Hollow.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	1.00	1.00	1.80
$\hat{N}$ (± 95% CI)	5 (15)	0 (0)	49 (145)
Mean Total Length (± 95% CI)	134 (0)	0 (0)	65 (7)
Mean Weight (± 95% CI)	23.6 (0.0)	0.0 (0.0)	3.0 (0.6)

14 riffles were snorkeled and 6 riffles were electrofished.

Table 5D-11. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in pools of Twomile Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	2.00	1.75	0.93
$\hat{N}$ (± 95% CI)	675 (200)	328 (94)	4054 (1317)
Mean Total Length (± 95% CI)	141 (15)	66 (8)	60 (1)
Mean Weight (± 95% CI)	30.2 (8.3)	2.8 (o.2)	2.1 (0.2)

40 pools were snorkeled and 10 pools were electrofished.

Table 5D-12. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in riffles of Twomile Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	1.00	2.00	2.06
$\hat{N}$ (± 95% CI)	0 (0)	139 (203)	1369 (610)
Mean Total Length (± 95% CI)	0 (0)	60 (4)	55 (2)
Mean Weight (± 95% CI)	30.2 (8.3)	2.8 (0.2)	2.1 (0.2)

32 riffles were snorkeled and 10 riffles were electrofished.

Table 5D-13. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in pools of Meadow Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	3.43	0.18	9.80
$\hat{N}$ **(± 95% CI)**	708 (421)	1597 (981)	19 (33)
Mean Total Length **(± 95% CI)**	166 (16)	68 (2)	69 (21)
Mean Weight **(± 95% CI)**	44.8 (11.3)	3.0 (0.3)	3.2 (0.0)

56 pools were snorkeled and 10 pools were electrofished.

Table 5D-14. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in riffles of Meadow Run.

Species	Adult brook trout	Young-of-year brook trout	Blacknose dace
Calibration ($\hat{R}$)[1]	2.03	1.00	1.00
$\hat{N}$ **(± 95% CI)**	63 (73)	1921 (1386)	0 (0)
Mean Total Length **(± 95% CI)**	128 (8)	68 (2)	0 (0)
Mean Weight **(± 95% CI)**	18.1 (4.3)	3.0 (0.4)	0.0 (0.0)

25 riffles were snorkeled and 10 riffles were electrofished.

Table 5D-15. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in pools of Wildcat Hollow.

Species	Adult brook trout	Young-of-year brook trout
Calibration ($\hat{R}$)[1]	3.00	1.00
$\hat{N}$ (± 95% CI)	183 (240)	160 (106)
Mean Total Length (± 95% CI)	148 (25)	69 (5)
Mean Weight (± 95% CI)	35.5 (8.1)	2.9 (0.2)

17 pools were snorkeled and 5 pools were electrofished.

Table 5D-16. Calibration ratio ($\hat{R}$), population estimates ($\hat{N}$), length (mm), and weight (g) for all fish species in riffles of Wildcat Hollow.

Species	Adult brook trout	Young-of-year brook trout
Calibration ($\hat{R}$)[1]	1.00	1.00
$\hat{N}$ (± 95% CI)	11 (19)	86 (54)
Mean Total Length (± 95% CI)	111 (0)	64 (9)
Mean Weight (± 95% CI)	12.4 (0.0)	2.7 (0.6)

16 riffles were snorkeled and 5 riffles were electrofished.

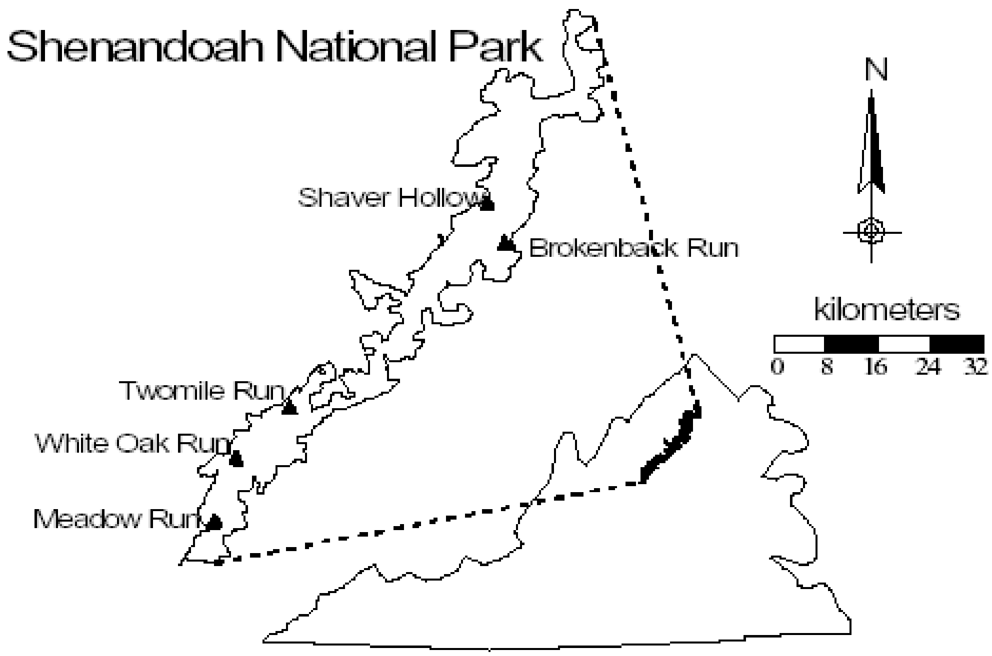


Figure 5D-1. Five watersheds in Shenandoah National Park, Virginia sampled for habitat and fish populations in 1994.

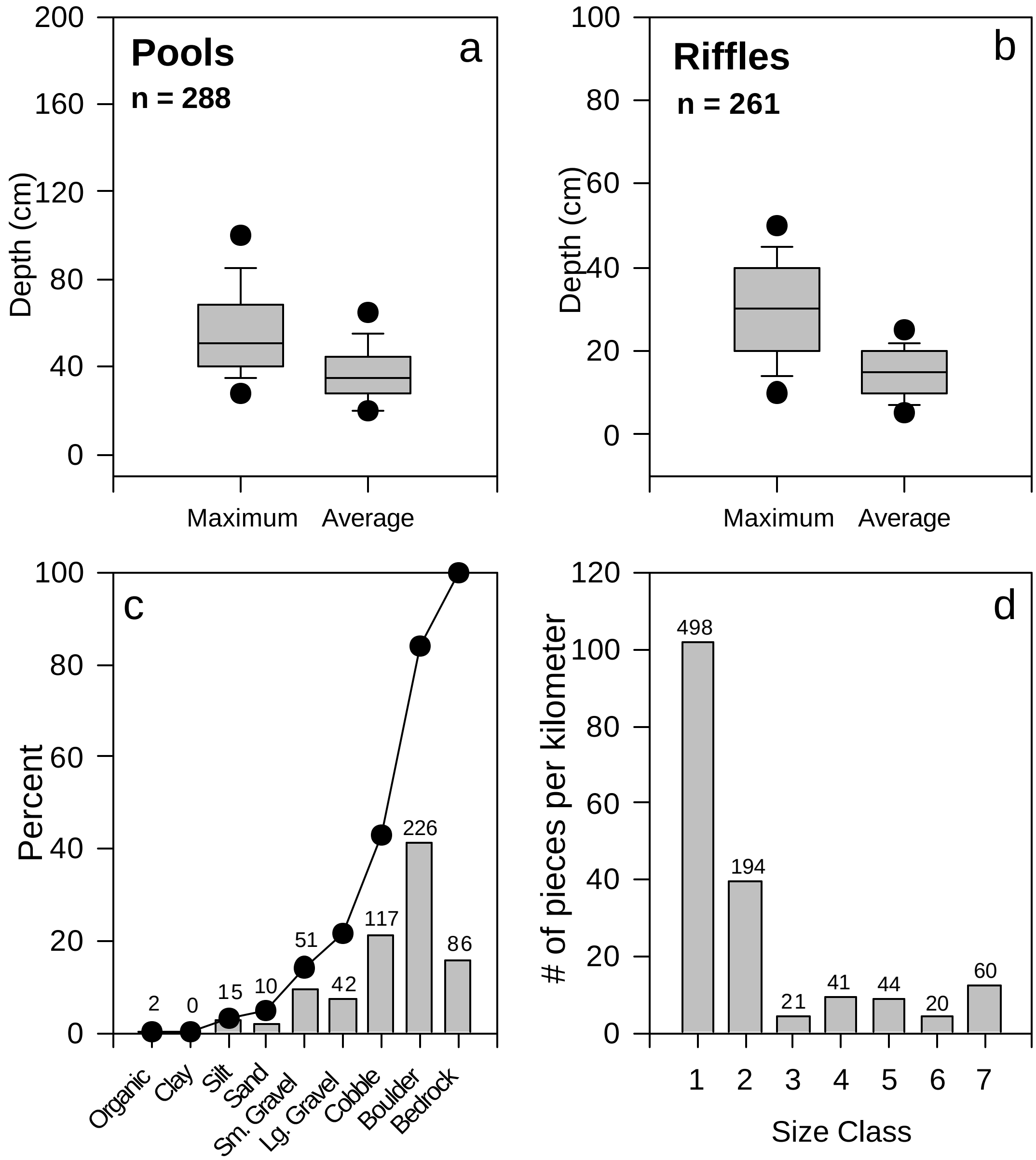


Figure 5D-2. Brokenback Run Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

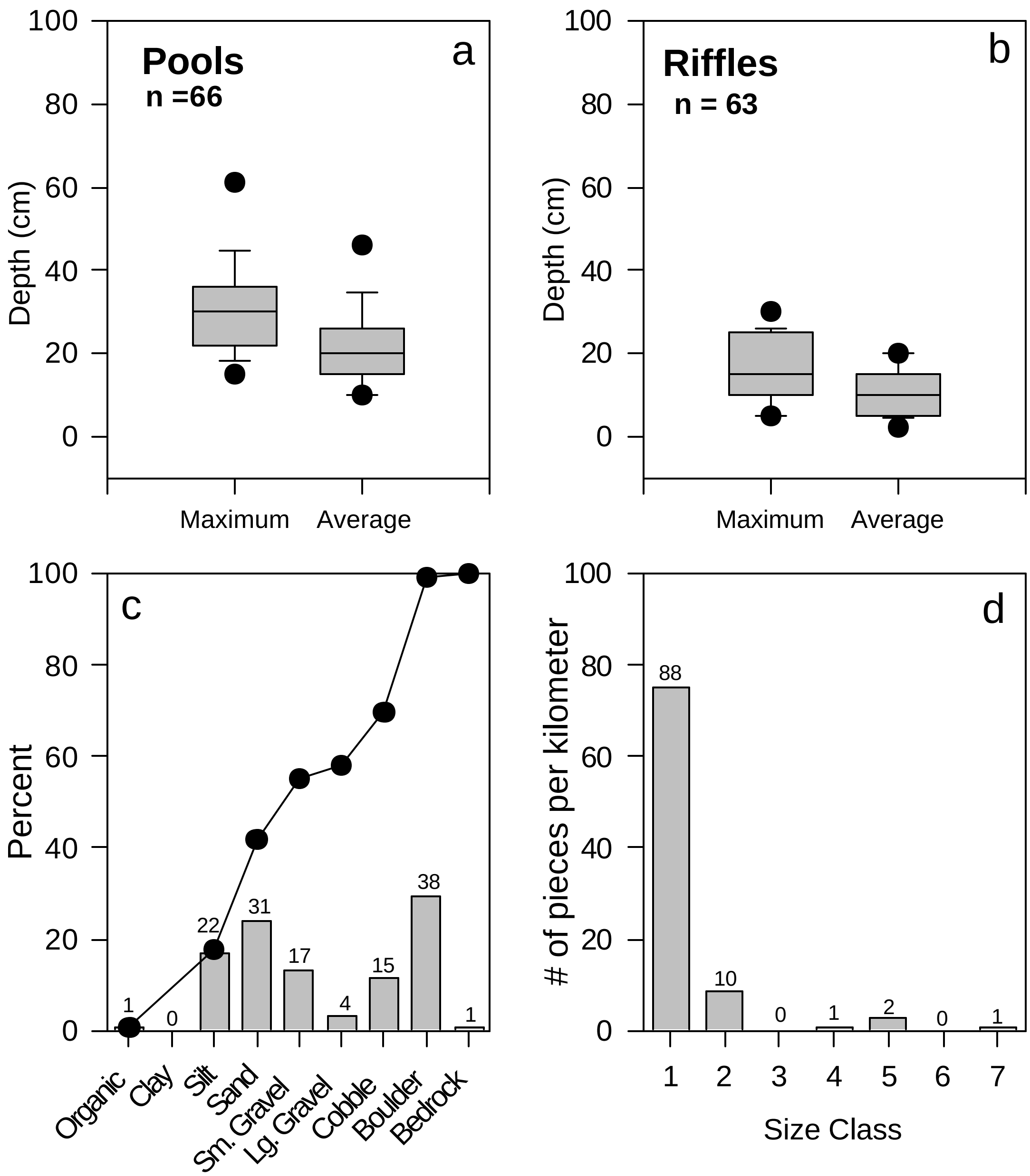


Figure 5D-3. Weakley Hollow Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

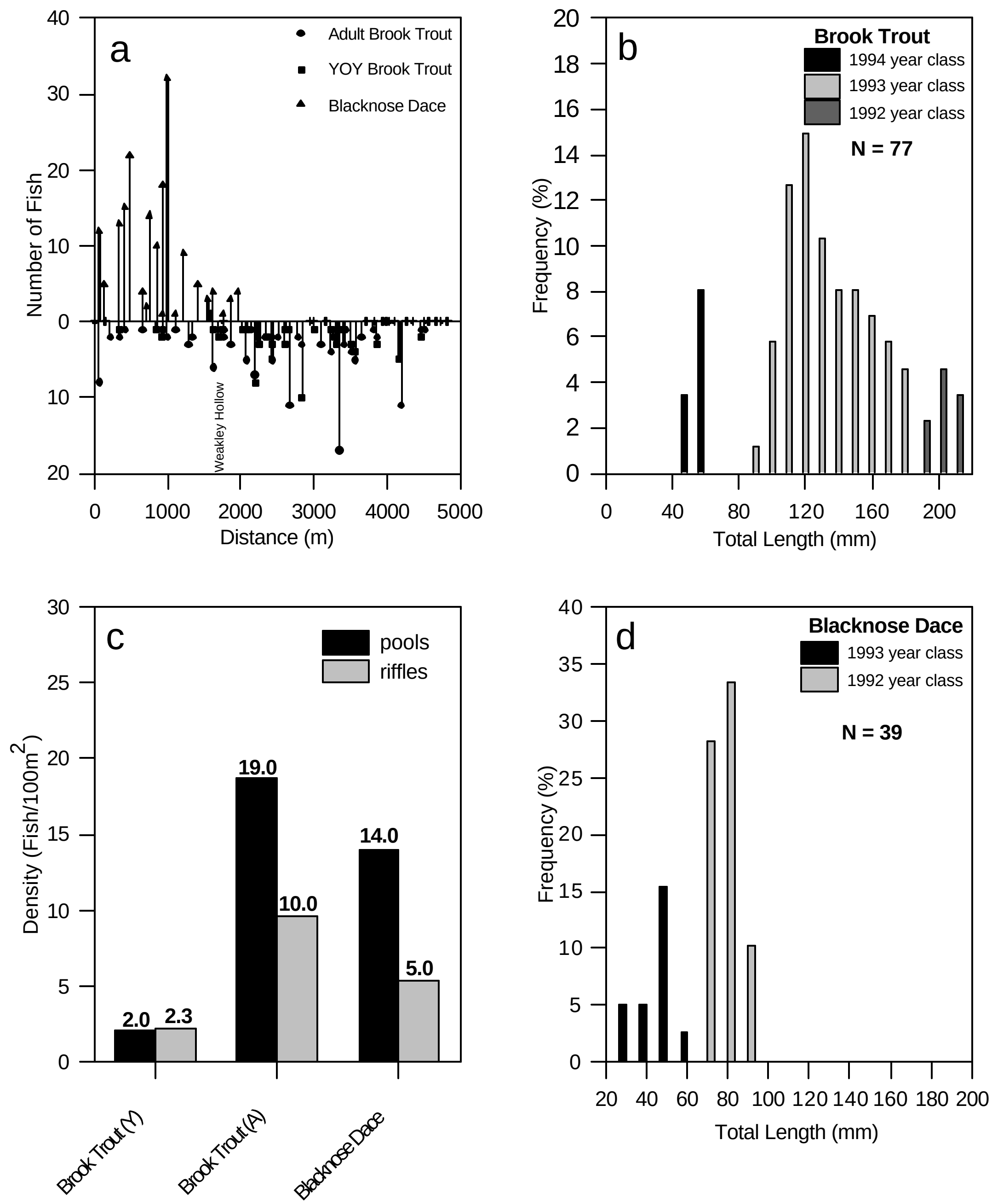


Figure 5D-4. (a) Distribution of fish species, (b) Length frequency of brook trout, and (c) Densities of fish species for pools and riffles in Brokenback Run. Numbers above bars represent actual density. (d) Length frequency distribution of blacknose dace in Brokenback Run.

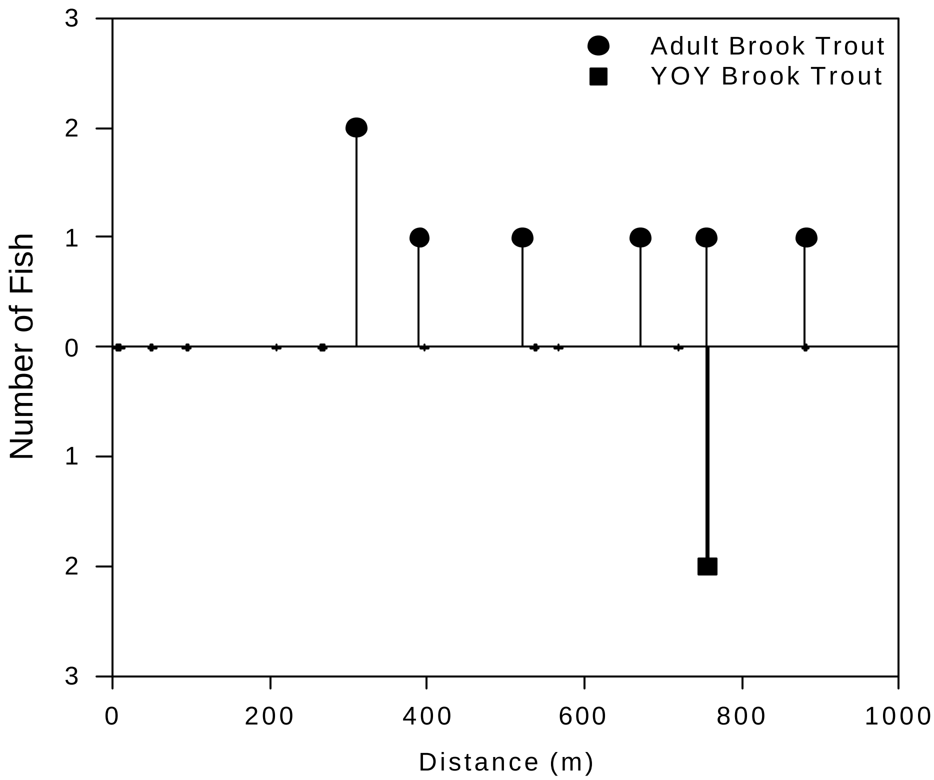


Figure 5D-5. Distribution of fish in Weakley Hollow.

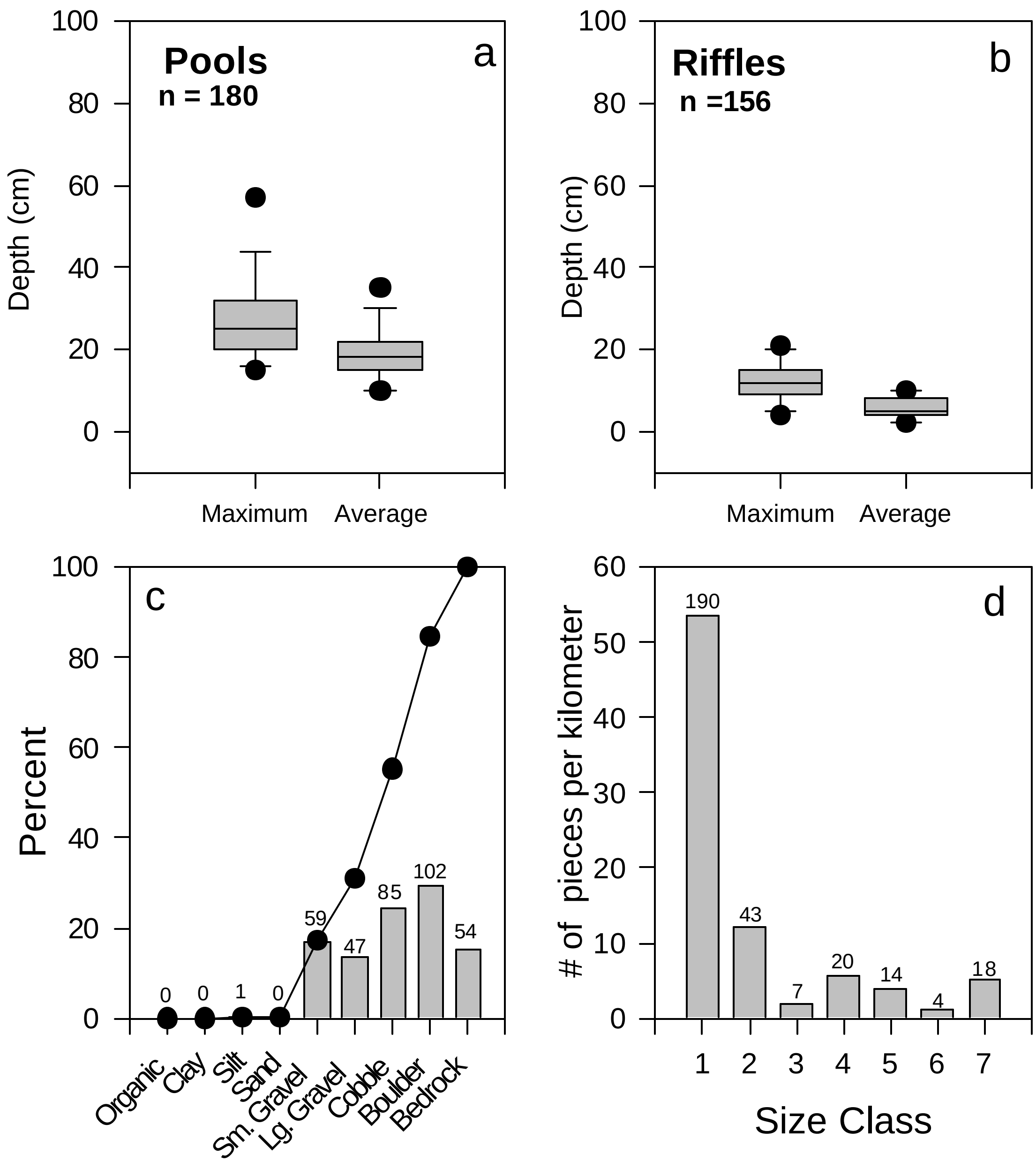


Figure 5D-6. White Oak Run Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

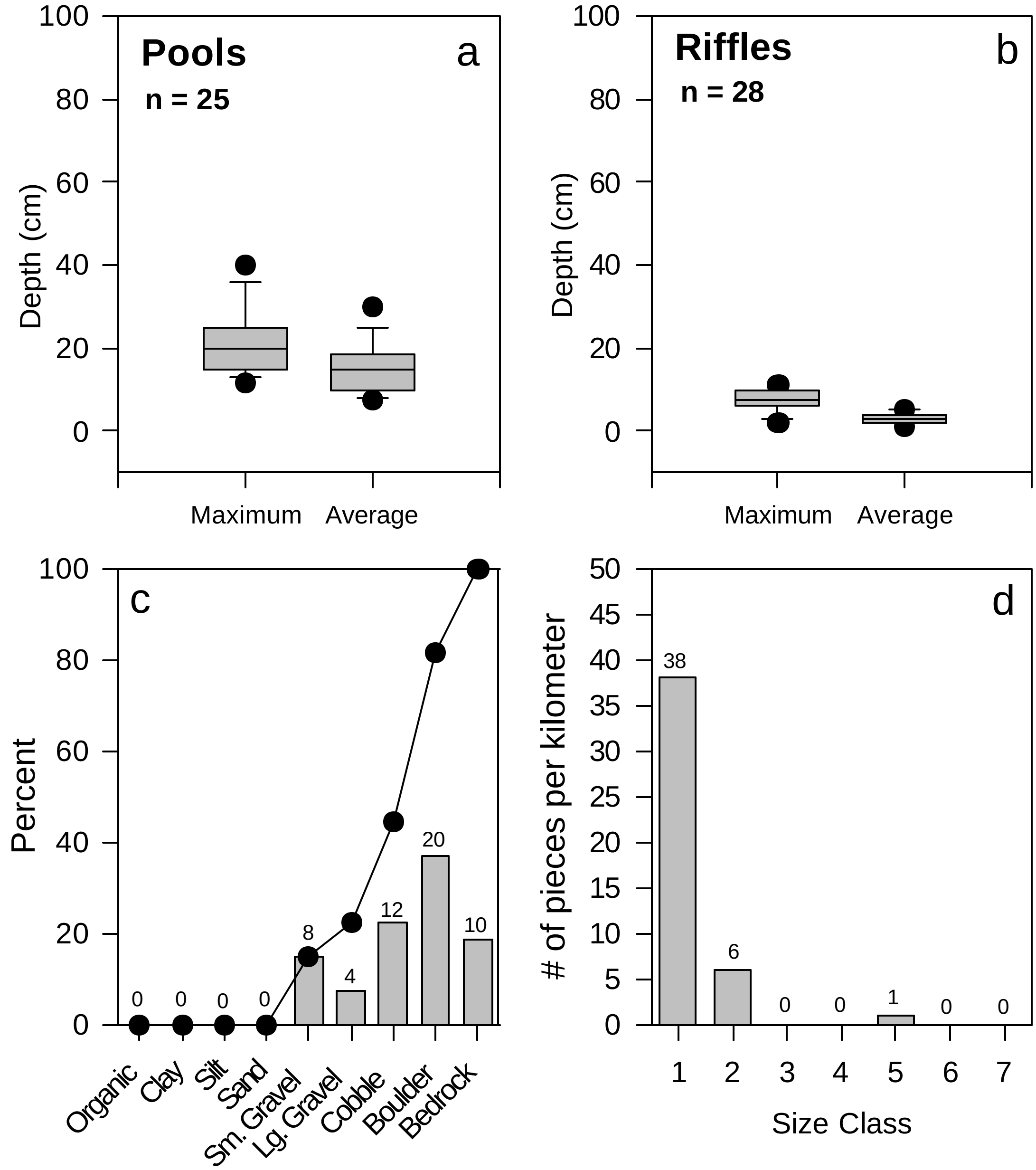


Figure 5D-7. Luck Hollow Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

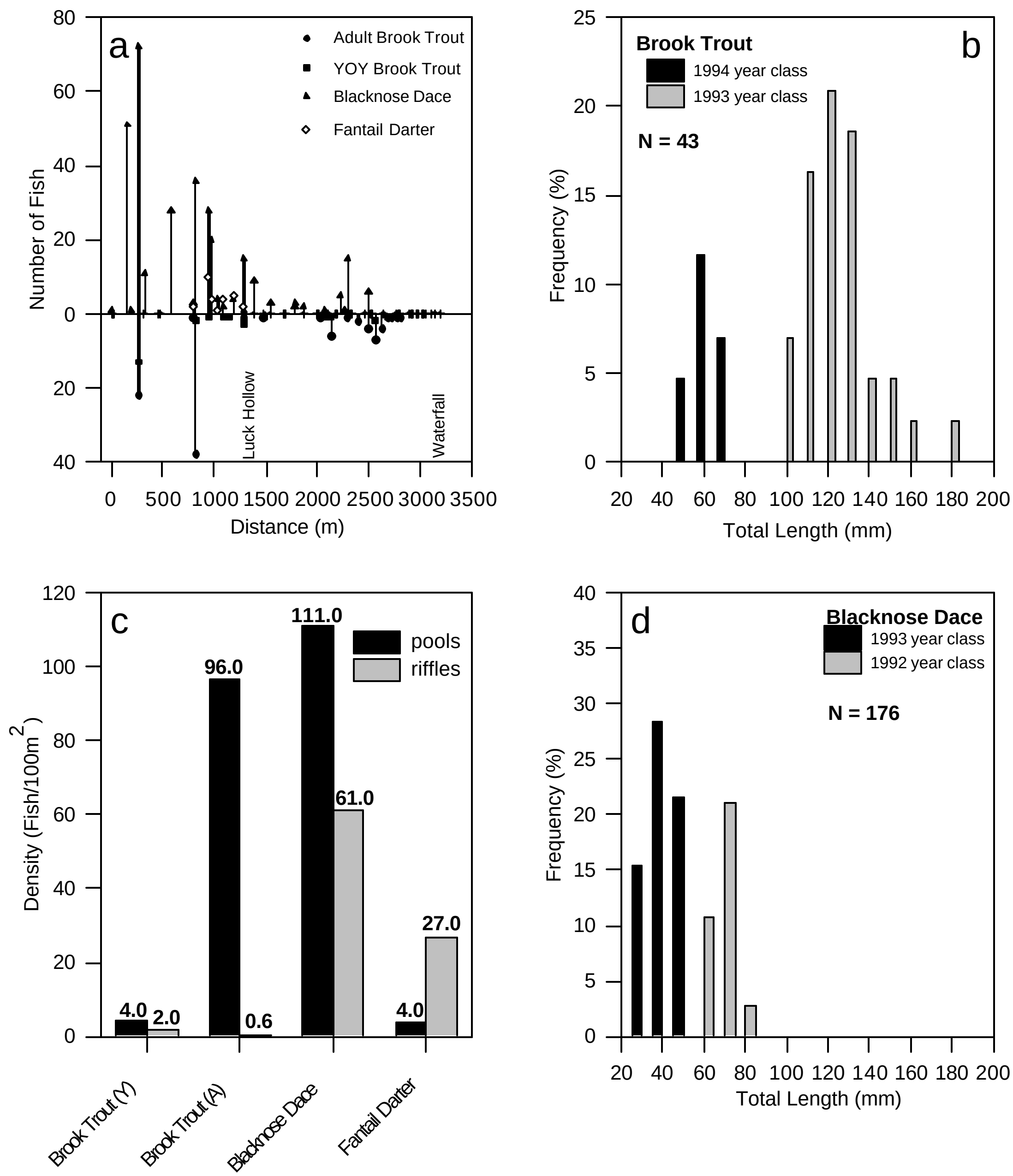


Figure 5D-8. (a) Distribution of fish species, (b) Length frequency of brook trout, and (c) Densities of fish species for pools and riffles in White Oak Run. Numbers above bars represent actual density. (d) Length frequency distribution of blacknose dace in White Oak Run.

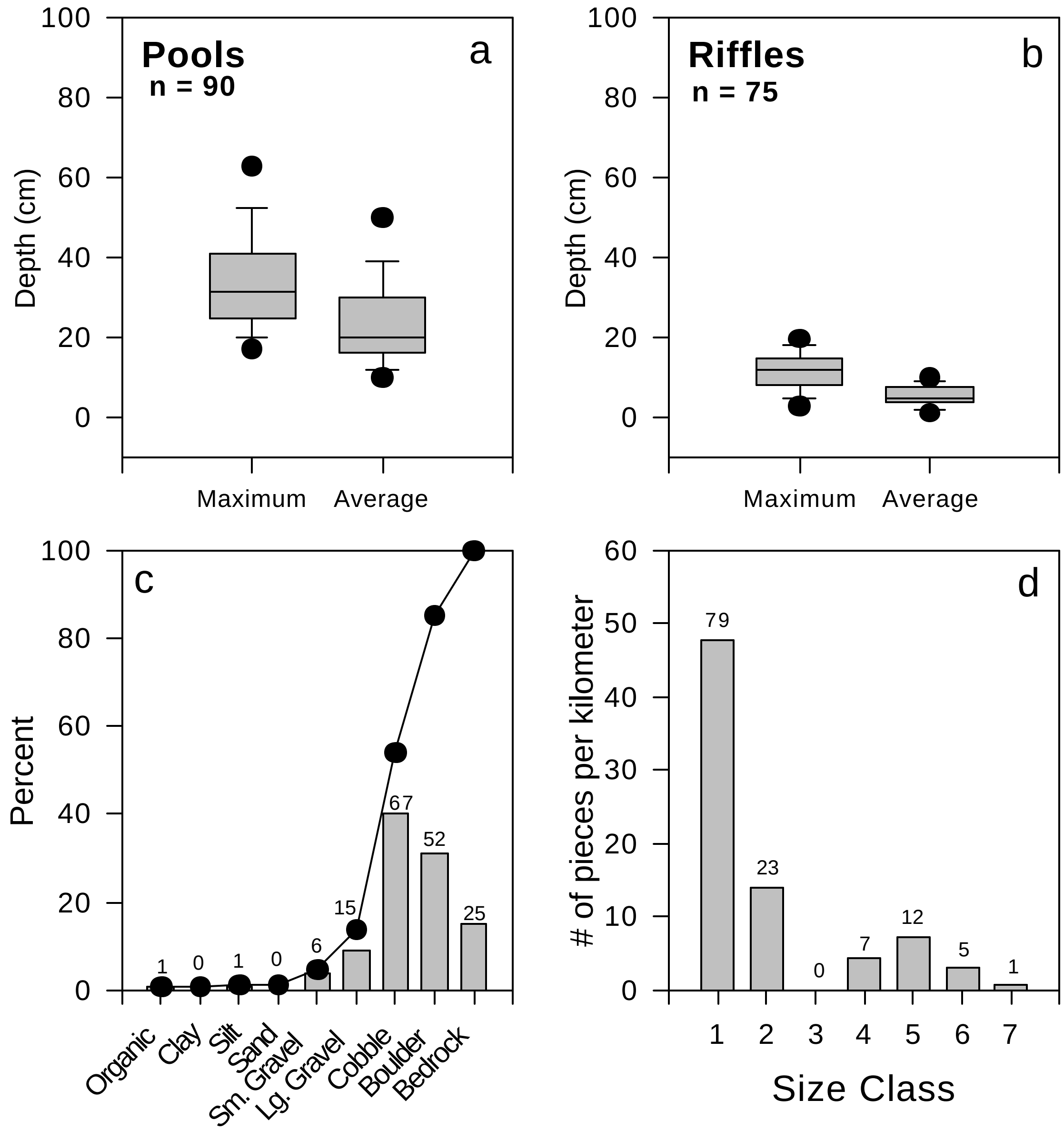


Figure 5D-9. Shaver Hollow Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

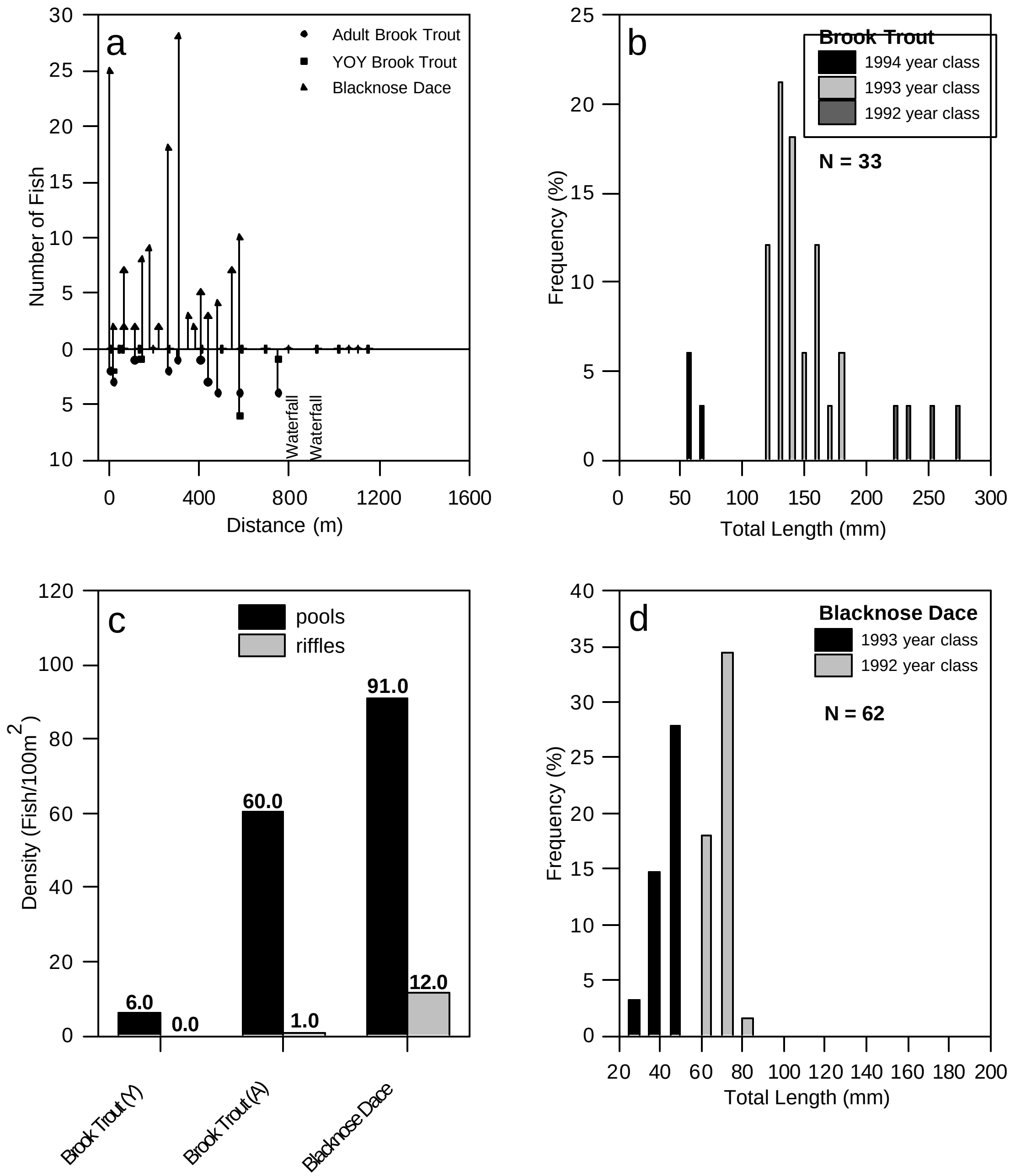


Figure 5D-10. (a) Distribution of fish species, (b) Length frequency of brook trout, and (c) Densities of fish species for pools and riffles in Shaver Hollow. Numbers above bars represent actual density. (d) Length frequency distribution of blacknose dace in Shaver Hollow.

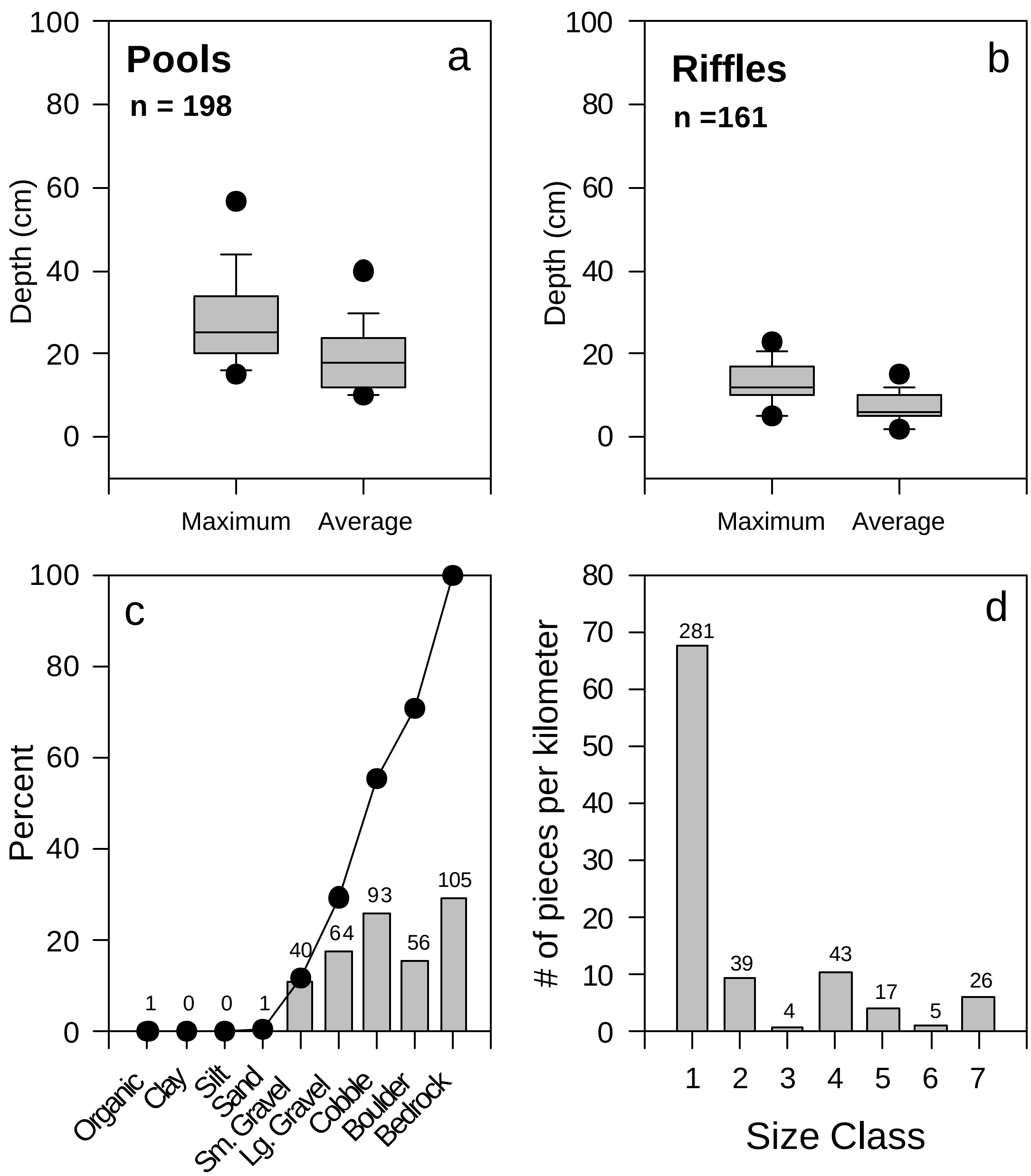


Figure 5D-11. Twomile Run Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

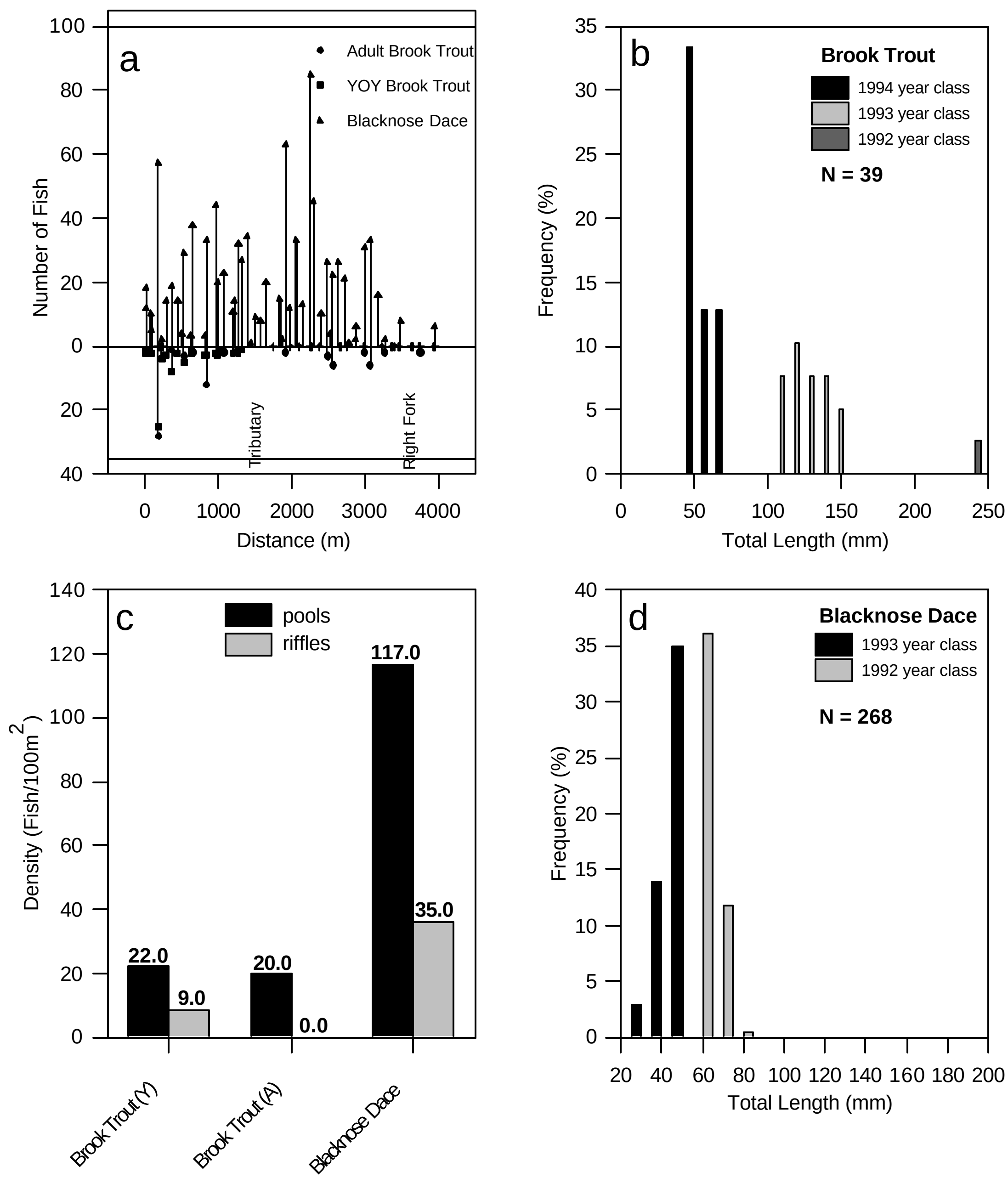


Figure 5D-12. (a) Distribution of fish species, (b) Length frequency of brook trout, and (c) Densities of fish species for pools and riffles in Twomile Run. Numbers above bars represent actual density. (d) Length frequency distribution of blacknose dace in Twomile Run.

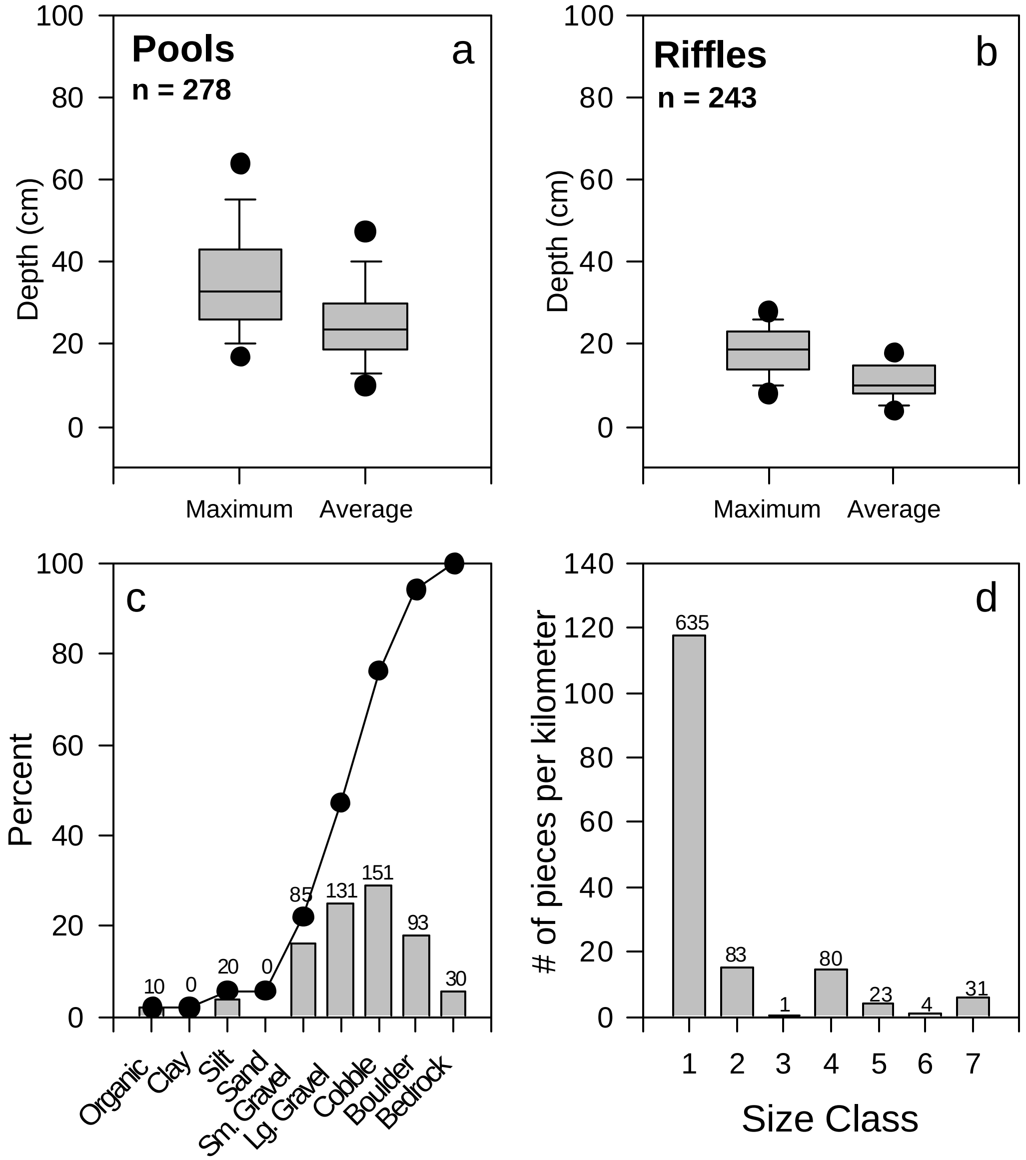


Figure 5D-13. Meadow Run Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

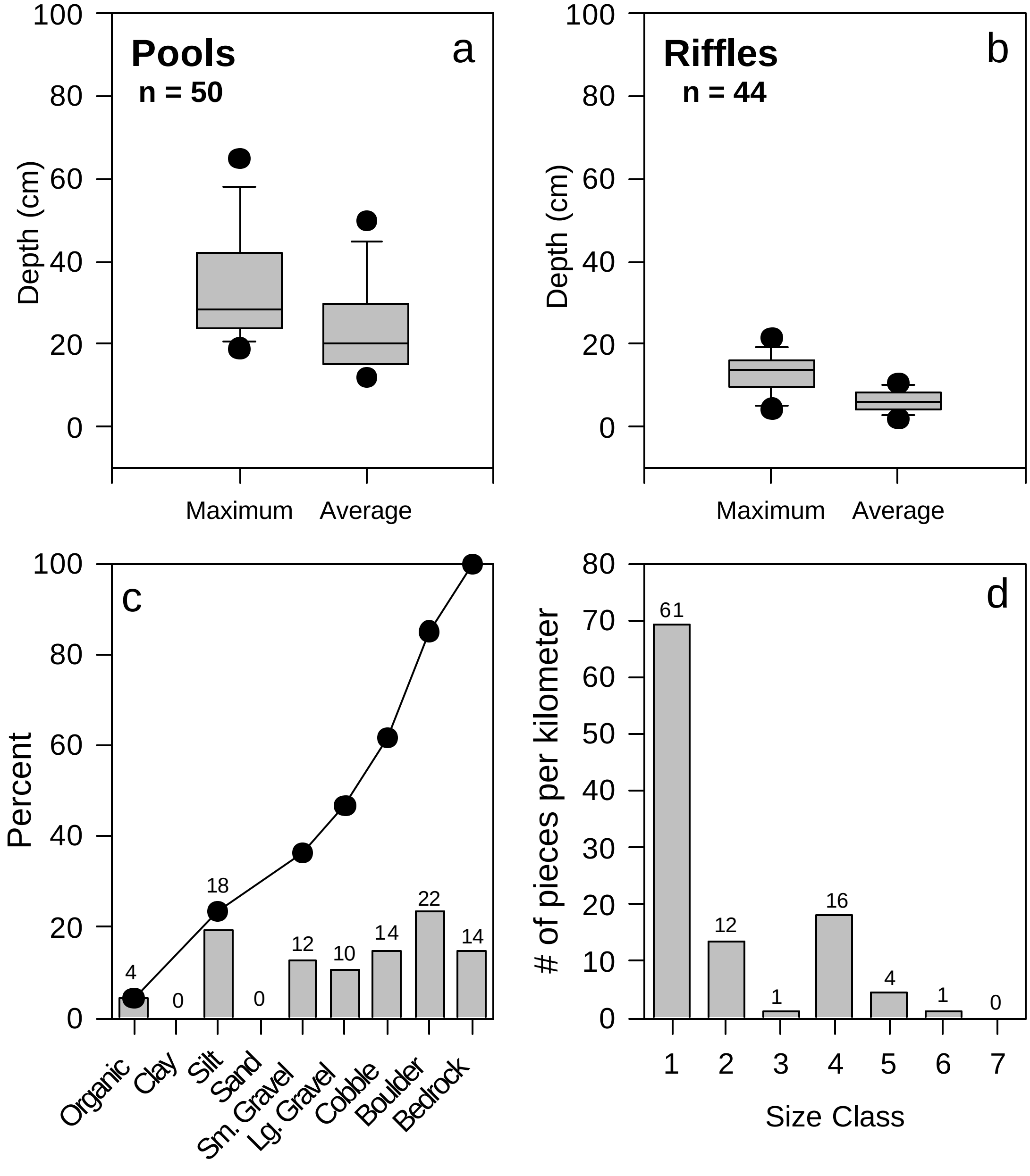


Figure 5D-14. Unnamed tributary Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

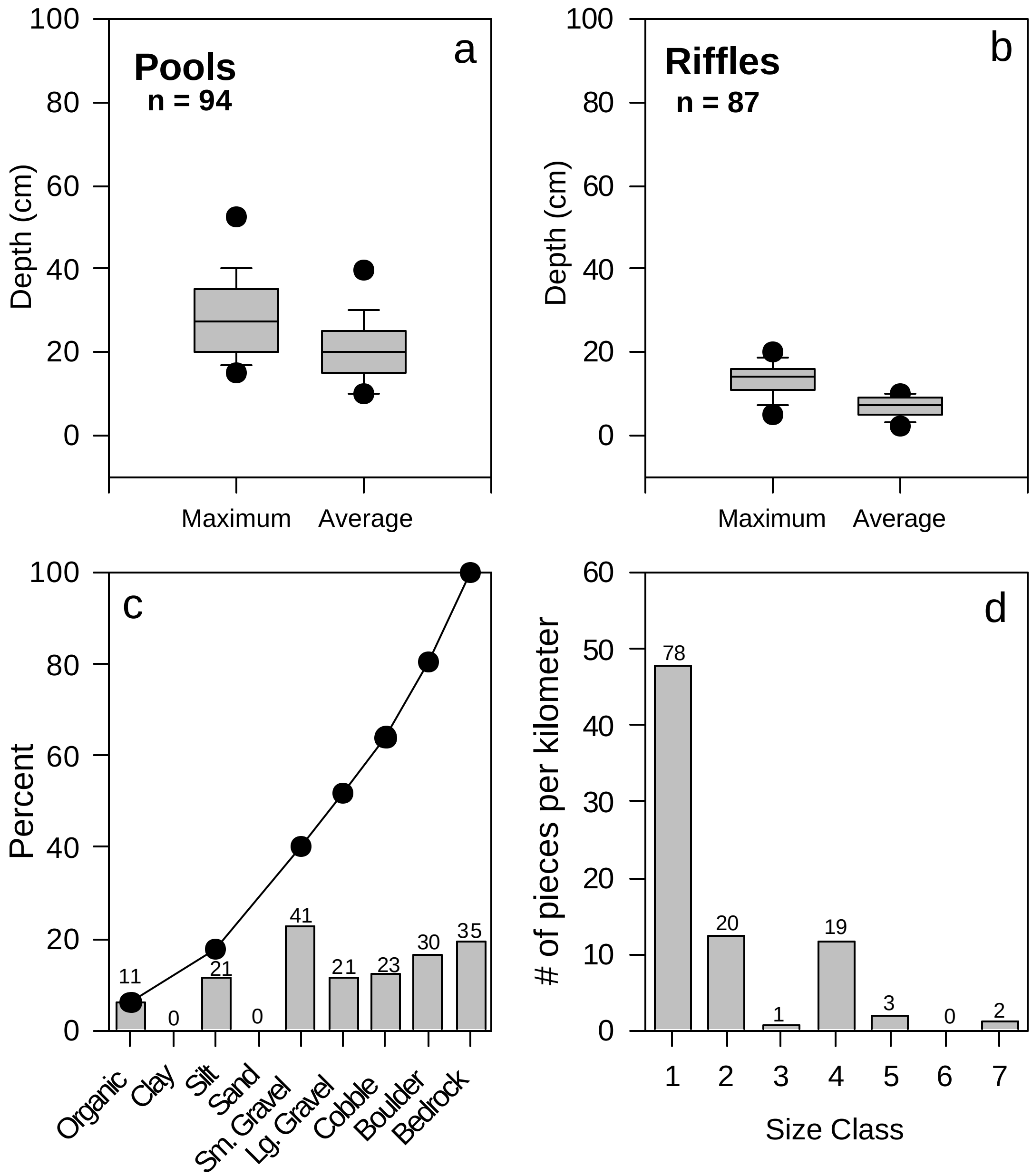


Figure 5D-15. Wildcat Hollow Habitat. Boxplots of maximum (a) and average (b) depths for pools and riffles. Boxes enclose the middle 50% of observations, capped lines below and above boxes represent the 10% and 90% quantiles, respectively, and the solid line in the box represents the median. Dominant substrate (c); bars represent frequency (percent), dots represent cumulative percent, and numbers above bars are total numbers of units in which the size class was dominant. Pieces of large woody debris per kilometer of stream by size class (d), bars represent numbers per mile and numbers above bars are the total number of pieces in each size class.

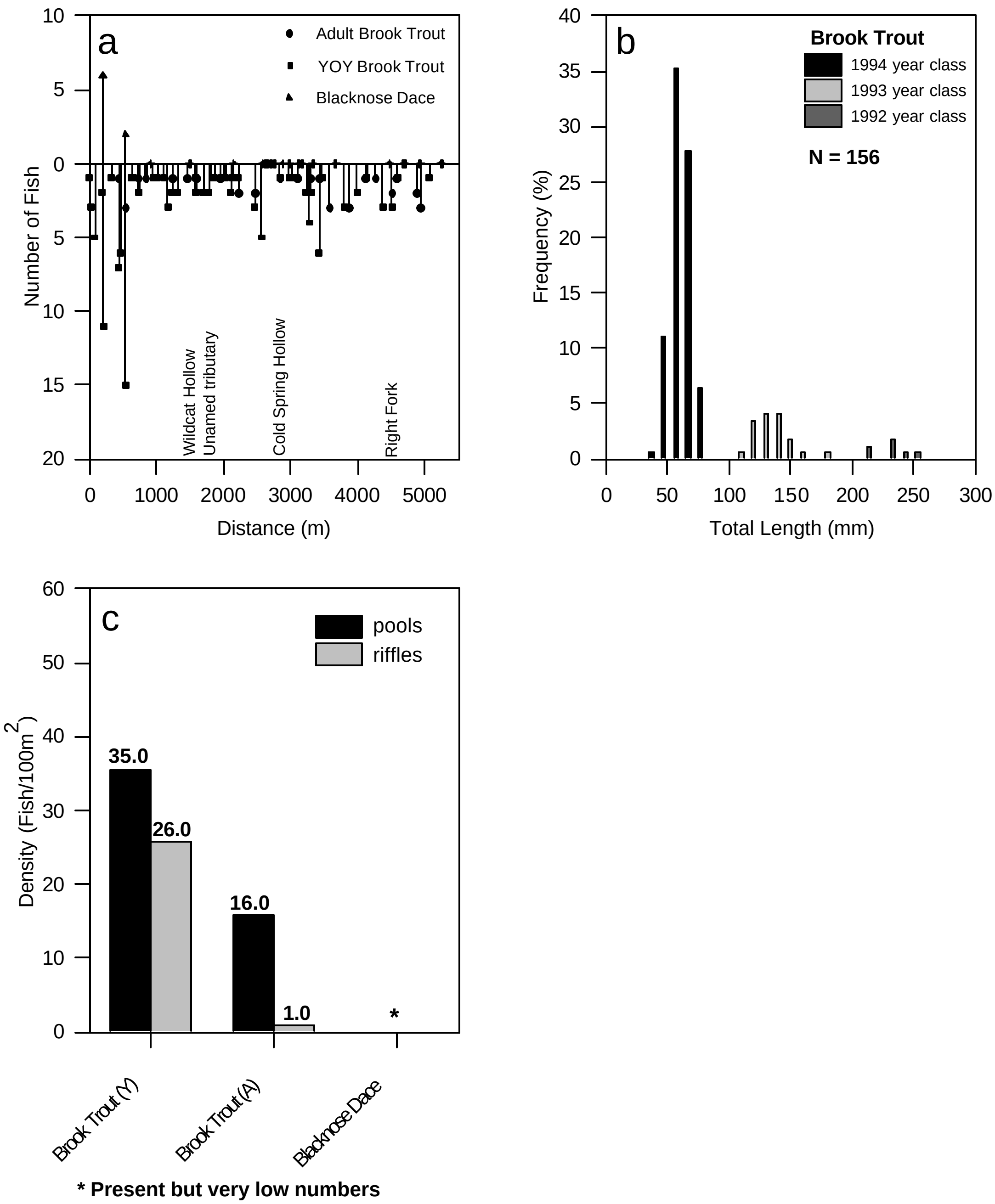
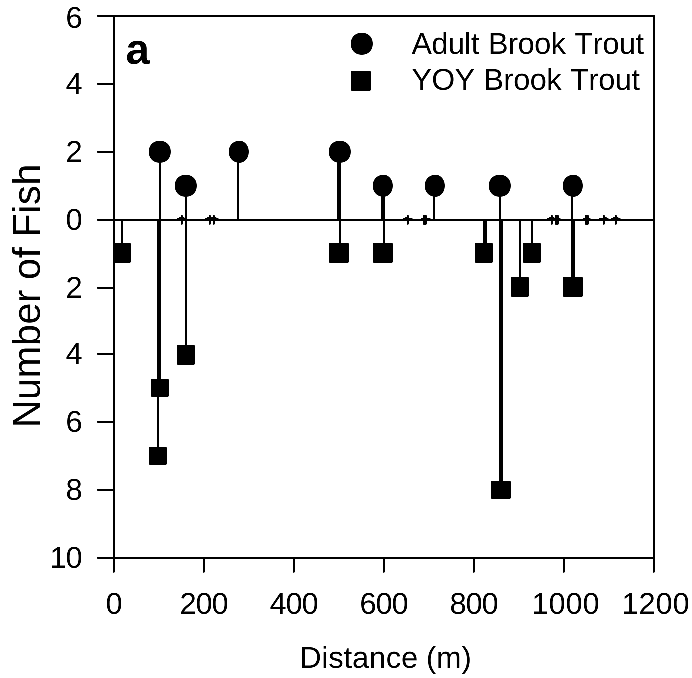


Figure 5D-16. (a) Distribution of fish species, and (b) Length frequency of brook trout, and (c) Densities of fish species for pools and riffles in Meadow Run. Numbers above bars represent actual density.



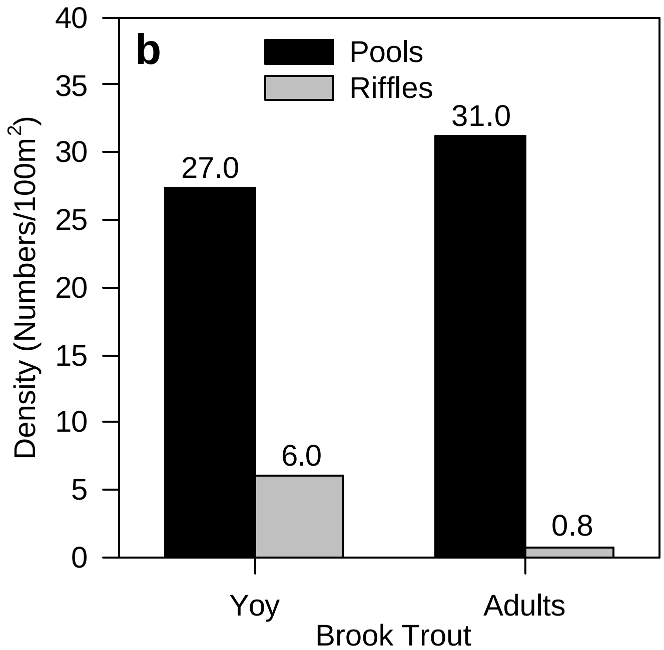


Figure 5D-17. (a) Distribution of fish, and (b) Densities of brook trout in Wildcat Hollow. Numbers above the bars represent actual density.